1-1-2004

Diel Activity Patterns, Space Utilization, Seasonal Distribution and Population Structure of the Yellow Stingray, Urobatis jamaicensis (Cuvier, 1817) in South Florida with Comments on Reproduction.

Daniel P. Fahy
Nova Southeastern University Oceanographic Center, fahyd@nova.edu

Nova Southeastern University Oceanographic Center

Diel Activity Patterns, Space Utilization, Seasonal Distribution and Population Structure of the Yellow Stingray, *Urobatis jamaicensis* (Cuvier, 1817) in South Florida with Comments on Reproduction.

Master's Thesis

Daniel P. Fahy

Major Professor

Richard E. Spieler, PhD

Submitted as a Thesis to the Faculty of Nova Southeastern University Oceanographic Center in partial fulfillment of the requirements for the degree of Master of Science with specialty in:

Marine Biology

Nova Southeastern University
2004

Abstract

The yellow stingray, *Urobatis jamaicensis* is the most common elasmobranch in the coastal waters of Southeast Florida. Despite their common occurrence the ecology of yellow stingrays remains poorly understood. In particular, yellow stingray daily movements, space utilization, seasonal distribution and population structure have not been described. This study was conducted to address the lack of knowledge of these fundamental life history parameters and to provide further information on the ecology of *U. jamaicensis* in coastal waters of Broward County, Florida.

The activity patterns and space utilization of *U. jamaicensis* were assessed by manual tracking with ultrasonic telemetry. Telemetry tracking of 17 stingrays was conducted from January 1998 to September 2001 with data presented on eight individuals tracked for a full diel cycle (24 h). Tracking data was analyzed with the Animal Movement Analysis Extension (AMAE) in Arcview® GIS to provide graphical representation of observed movements within the complex series of reef terraces and hardbottom communities of Broward County. Bottom topography had considerable influence on the space utilization of stingrays and observed movements varied with location in relation to proximity from the reef edge/sand interface. Movement was intermittent throughout the day, but displayed a highly significant increase during the nocturnal and crepuscular phases in comparison to diurnal movements. Nearly all stingrays demonstrated confined movements and indicated strong site fixity, which may imply the existence of home ranging behavior. The 95% (total 24h activity space) and the 50% (core area) Kernel Utilization Distributions (KUD) were constructed to visually display the shape and size of activity spaces. The data was pooled together for the eight individuals tracked for a full diel cycle and divided into four 6-h shifts. Statistically significant larger activity spaces for both the 95% KUD and the 50% KUD were observed during the nocturnal activity phase.

Seasonal distribution was assessed to determine animal residency within the study site and ascertain the occurrence and temporal patterns of onshore/offshore movements. Stationary visual fish census techniques (point counts) from several studies conducted in Broward County from January 1998 to December 2003 were combined to determine the level of abundance across three reef tracts, throughout the entire length of the county. Data was tested for monthly and seasonal differences and for variation between reefs. Analysis of seasonal distribution established population residency is year-round with no indication of offshore emigration associated with a temperature preference.

Population structure analyses were conducted to determine the sex ratio and size distribution of *U. jamaicensis* to examine any potential gender segregation or ontogenetic partitioning. The sex ratio was compared for differences monthly, seasonally and between reefs for expected vs. observed frequencies. Only spring observations (March, April, May) evidenced a statistically significant difference from a 1:1 ratio, where females dominated the inshore observations 20F:8M. Average size of both genders was 333mm TL, however, females dominated the larger size classes (>350mm TL). Few neonates were observed during this study with most observations occurring in shallow inshore water (<6m depth), suggesting a nearshore nursery. Increased abundance and presence on the offshore reef among intermediate size classes (250-299mm to 300-349mm) suggests a potential ontogenetic shift to deeper water. Observations on the seasonal patterns of the reproductive condition of female yellow stingrays are also provided.

Acknowledgments

This thesis has been a long time in the making and I've had the opportunity and the pleasure to meet many people and make many friends during the process. I'd like to express my appreciation to the many Nova people who worked as divers, boat handlers and boat personnel that made the telemetry tracking portion of this study possible: Debbie Abercrombie, Courtney Arena, Demian Chapman, Jessica Craft, Susan DeVictor, Ian Gibson, Amy Hall, Heather Halter, Aaron Hartz, Mike Hoke, Matt Mitchell, Ryan Moyer, Liam Murphy, Dr. Robin Sherman and Ray Wolcott.

I'd like to especially thank my lab mates, who not only helped with the tracking study, but in every other aspect of the data collection. Paul Arena, Rob Baron, Brian Ettinger and Fleur Ferro for all of their field assistance and contributions from their individual theses projects, which helped establish the seasonal distribution data for my study. Brian Buskirk for diving and driving the LUCY a number of times. Pat Quinn for his valuable computer know-how, which saved a bunch of data I thought, was lost forever. Lance Jordan for driving me out to capture stingrays and all his much-appreciated assistance with Statistica. Brian Walker for his assistance during tracking and for providing me with LADS images for my GIS work and a number of excellent map images for my study site figures. You are all nuts, so I can see quite easily, just how perfect I fit into this Ichthyology Lab. Thank you all for making it fun.

I'd like to thank my Major Professor, Dr. Richard Spieler for providing numerous editorial comments, for all of his assistance and guidance in establishing this projects original concept and for allowing me to mold it into the finished product. You have helped me to improve my abilities as a scientist, you have been a good friend, but most of all you have been very patient over the years it has taken to finish this work. I would also like to thank my committee members for their comments, Dr. Mahmood Shivjii and especially Dr. David Gilliam for also allowing me the time from our busy work schedule to continue writing, I would probably still be on the computer if you weren't so understanding.

My family has constantly supported my continued education, even though they have teased me relentlessly over the years for my eternal student status. My parents George and Patricia Fahy, my sister Theresa and her husband David have always encouraged me to find what makes me happy and then help open as many doors as possible to achieve it, thank you ever so much. One person more than any, that I wish could have shared in this accomplishment is my Gram, Mary Fahy. She was a second mother for me my entire life and simply the most incredible person her entire life, I dedicate this writing in her memory.

Last but not least it has been my honor and privilege to share this amazing experience with my wife Elizabeth, whom I've had the most unbelievable fortune to work with side by side over the years. Thank you so much for all your long hours on the boat, all your valuable editing skills, your constant support and shared enthusiasm and most of all for saying yes in Galway on my Gram's birthday. You have not only made me a better scientist, but a better person and I look forward to a lifetime of traveling, conducting research together and creating lots of little scientists. You are the one that has been truly amazing!

Table Of Contents

Table of Contents (continued)

List of Figures

List of Tables

List of Appendices

1.0 Project Description

1.1 Introduction

The yellow stingray, *Urobatis jamaicensis* (Cuvier, 1817) is the most common elasmobranch found inhabiting the coastal waters of southeast Florida (Robins *et al*, 1986). However, like most elasmobranchs, the life history of *U. jamaicensis* is still poorly known. Past research has predominantly focused on laboratory conducted physiological studies; only a few field investigations have addressed the basic ecology of yellow stingrays under natural conditions (Yañez-Arancibia & Amezcua-Linares, 1979, Young, 1993, Quinn, 1996, and Sulikowski, 1996). The majority of the existing biological information on *U. jamaicensis* is found in regional fish identification books (Bigelow & Schroeder, 1953, Randall, 1968, Robins *et al*, 1986, Böhlke & Chaplin, 1993, M^{c}Eachran & Fechhelm, 1994, Hoese & Moore, 1998 and Humann, 2002). However, these field guides typically consist of conflicting or outdated materials and are often restricted to the species description and range of occurrence. The basic ecology of *U. jamaicensis*, in particular their daily movements, periodicity of activity and seasonal distributions has yet to be described and was therefore undertaken as the purpose of this study.

Bell (1991) described searching behavior as "an active movement by which an animal finds or attempts to find resources" and highlighted the importance of this behavior for acquiring the essential resources (e.g. food, habitat & mate) to ensure survival and reproductive potential. Searching behavior involves a dynamic relationship between various ecological variables (e.g. landscape, behavior, population structure and individual interactions), all of which have a spatio-temporal link that collectively

influence the life history of an organism. Although the localization and timing of these factors may involve a complex series of events, the achievement of social and spatial interactions requires movement. Determining the diel activity patterns and space utilization for individual animals and the seasonal distributions of the population are among the first steps in addressing and understanding the life history of a species. I selected telemetry tracking and presence/absence sampling as reliable methods for establishing an understanding of the movements and spatial ecology of yellow stingrays. Gender and age class segregation are commonly reported among many elasmobranchs (Babel, 1967, Klimley, 1987, Sims *et al,* 2001) and may be important factors in determining the seasonal population dynamics of yellow stingrays. Thus, I analyzed the sex ratios and size classifications from several studies to aid in providing a basis for determining the structure of the local population of *U. jamaicensis* in Broward County, Florida.

1.2 Species Description

Yellow stingrays are small in size with a maximum total length (TL) reported at 760 mm (Lieske & Meyers, 2002), however, this is dramatically larger than the maximum size reported in most studies ($\overline{X}$ = 425 mm TL) (Bigelow & Schroeder, 1953, LaMarca, 1961, Yañez-Arancibia & Amezcua-Linares, 1979, Sulikowski, 1996). The maximum size of *U. jamaicensis* has been inconsistent throughout the literature with most authorities simply cross-referencing one another between updated editions of field guides (Appendix A). Consequently the size has continually grown over the years and because no indication is given for the source of information, the possibility exists for a typographical error or some other inaccuracy within the recognized literature.

Yellow stingrays, like all urolophids, are characterized by rounded pectoral fins and a well-developed caudal fin supported by cartilaginous rays. Coloration is extremely variable and often forms a variety of reticular patterns or vermiculations (Böhlke & Chaplin, 1993, M^{c}Eachran & Fechhelm, 1994 and Hoese & Moore, 1998). The general appearance of South Florida specimens (Figure 1) is of a brownish or greenish background with numerous yellow, gold and white spots justifying their common name: yellow stingray (Bigelow & Schroeder, 1953, Böhlke & Chaplin, 1993, M^{c}Eachran & Fechhelm, 1994). For a more thorough description of the various color patterns with illustrated examples refer to Bigelow and Schroeder (1953).

Figure 1. *Urobatis jamaicensis* resting along a typical South Florida hardbottom habitat (1st reef, Broward County).

1.3 Species Range and Distribution

The species range is from Brazil to Florida in the tropical to sub-tropical western North Atlantic and adjacent waters (Robins *et al*, 1986). A single anomalous report from Cape Lookout, North Carolina (June, 1911) dramatically extends their range north, but all other recorded accounts are south of Jupiter Inlet, Florida (Bigelow & Schroeder, 1953 and REEF, 2004). An extensive ichthyological survey employing multiple collecting techniques produced no records of *U. jamaicensis* landings or observations between Jupiter Inlet and New Smyrna Beach, Florida, including the Indian River Lagoon system and freshwater tributaries (Gilmore *et al*, 1981). Distribution occurs along both coasts of southern Florida (uncommon along the panhandle), Western Gulf of Mexico from Yucatan to the southern coast of Texas, down the Central and South American coasts to northern Brazil and widespread throughout the Caribbean (Bigelow & Schroeder, 1953, Randall, 1968, Robins *et al*, 1986, Hoese & Moore, 1988, Böhlke & Chaplin, 1993, Humann, 2002, REEF, 2004).

The range of *U. jamaicensis* is reported to overlap both of the related Atlantic urolophid species (*Urotrygon microphthalmum* and *Urotrygon venezuelae*), extending south to Northern Brazil (Bigelow & Schroeder, 1953). However, an extensive review on the distribution of batoids along the east coast of South America (Brazil, Uruguay and Argentina) only included *Urotrygon microphthalmum* among the listed species (Menni & Stehmann, 2000). Therefore, earlier reports may have involved the false-identification of *U. jamaicensis* in Brazil and mistakenly extended their range below the Caribbean portion of South and Central America. Future surveys along the northeast coast of South

America (Columbia to Brazil) are required to verify the accurate southern geographical range of *U. jamaicensis*.

1.4 Habitat

Urobatis jamaicensis commonly inhabits the coral reefs of South Florida and associated habitats, where they are typically found buried in sand or resting on rocky substrate (Robins *et al*, 1986). The maximum depth recorded for *U. jamaicensis* is 25m, however, they typically occur in shallow coastal waters including bays, inlets, harbors, and estuaries and occasionally "along sandy beaches to the water's edge" (Robins *et al*, 1986, M^{c}Eachran & Fechhelm, 1994, Humann, 2002). Most of the reported information comes from antiquated beach seining and trawl data or from casual observations while diving (Bigelow & Schroeder, 1953 and Humann, 2002). Adequate research is lacking to substantiate any habitat preference, seasonal occurrence or movement patterns of yellow stingrays anywhere throughout their distribution.

1.5 Classification and Interrelationships of Urolophidae

Urobatis jamaicensis is a member of the Urolophidae Family (round stingrays), which is composed of four recognized genera (*Urobatis*, *Urotrygon*, *Urolophus* and *Trygonoptera*). The family consists of (37) valid species worldwide with an additional four to six unidentified species in Australia and the Indo-Pacific (López & Bussing, 1998 and Compagno, 1999). There are a total of 16 amphi-American species of which 13 span the eastern Pacific coast from northern California to Chile, while only three species occur in the tropical Northwestern Atlantic (Appendix B). The strictly South American Atlantic species are *Urotrygon venezuelae* from the coastal waters of Colombia and Venezuela and *Urotrygon microphthalmum* along Venezuela and further south to João

Pessoa, Brazil, where it is considered abundant along the coast of Maranhão (Miyake & M^{c}Eachran, 1986, 1988 and Menni & Stehmann, 2000). As previously mentioned, extensive sampling of these southern regions is necessary to provide an accurate account of their distributions and determine if any overlap between these species and *U. jamaicensis* exists.

Recognizable differences between the gross physical characteristics of all three Western Atlantic species make identification to the specific level easy. A longer and slender tail relative to disc length, non-confluent lobes of the caudal fin and a more prominently pointed snout visually distinguish the genus *Urotrygon* from *Urobatis* (Bigelow & Schroeder, 1953 and Chirichigno & M^{c}Eachran, 1979). In addition to a characteristic color pattern, denticles or small tubercles on *U. jamaicensis* are limited to the dorsal mid-line and tail (Chirichigno & M^{c}Eachran, 1979). *Urotrygon venezuelae* have numerous small weak denticles with enlarged thorn-like denticles along the mid-line of the disc and tail and obtain a maximum known size of only 286 mm TL (Bigelow & Schroeder, 1953 and Miyake & M^{c}Eachran, 1986, 1988). *Urotrygon microphthalmum* have reduced eyes, sparse velvet-like denticles, lack thorns on the disc and tail and have a maximum reported size of 300 mm TL (Bigelow & Schroeder, 1953**,** Miyake & M^{c}Eachran, 1986 and Almeida *et al*, 2000).

M^{c}Eachran *et al* (1996) have suggested a division within the family, which removes the amphi-American species (*Urobatis* and *Urotrygon*) and classifies them separately into a new family as Urotrygonidae. Recent phylogenetic analyses have provided additional support for the division, indicating Urolophidae to be paraphyletic with the genus *Urolophus* basal among the myliobatoids (Lovejoy, 1996 and Dunn *et al*,

2003). This division has not gained wide acceptance (Moyle & Cech, 2000 and Menni & Stehmann, 2000) and most investigators still group all four genera together as Urolophidae (Compagno, 1999 and FISHBASE, 2004).

The genus *Urobatis* until recently was synonymous with *Urolophus*, which is now reserved only for the 16 remaining Australian and Indo-Pacific species (Compagno, 1999). Garmin (1913) first suggested the genus name *Urobatis*, and it was primarily used in medical literature on stingray injury and treatment (Campbell, 1951, Russell, 1953, 1955 and Russell & von Harreveld, 1954). Bigelow and Schroeder (1953) combined *Urobatis* with *Urolophus*, stating that Garmin's separation due to the absence or presence of protrusion of the snout was "to be of specific significance at the most". *Urobatis* remained synonymous with *Urolophus* until the doctoral work of Miyake (1988) reported several anatomical differences among the American species and re-established Garmin's original nomenclature. The resurrection of *Urobatis* was apparently overlooked for sometime; *Urolophus* subsequently remained used in reference to the publications of Bigelow & Schroeder (1953) on fishes of the Western North Atlantic. M^{c}Eachran & Fechhelm (1994) were first to acknowledge the genus correction and subsequently, most recent literature has applied *Urobatis* (Allen & Robertson, 1994, Lovejoy, 1996, M^{c}Eachran *et al*, 1996, Rodríguez-Romero *et al*, 1998, Compagno, 1999, Zamparo *et al*, 1999, Rosenberger, 2001, Valdez-González *et al*, 2001, Walker & Sherman, 2001, Dunn *et al*, 2003 and FISHBASE, 2004).

1.6 Species Related Research

Relatively little is known of the yellow stingray's life history and general ecology. Bigelow & Schroeder (1953) discussed the basic biology, description and distribution of

U. jamaicensis in a comprehensive study of Western North Atlantic Fishes. Descriptive comparisons among several urolophids have been conducted in Bigelow & Schroeder (1962), Dixon (1969) and additionally in Chirichigno & M^{c}Eachran (1979) the latter based on the discovery of a new urolophid species.

1.6.1. Anatomy, Physiology & Systematics

The common occurrence and size of *U. jamaicensis* make for an ideal experimental animal, which has lead to numerous physiological and ultrastructural studies. LaMarca (1961) conducted a thorough examination of the anatomy of the reproductive system in his Ph.D. dissertation. Phleger (1988) reported *U. jamaicensis* had the lowest skeletal lipid concentrations (0.1 - 0.6%) among 14 reef fishes analyzed in Jamaica. Sherman and Gilliam (1996) compared the Hepato-Somatic Indices (HSI) of several batoids and determined *U. jamaicensis* among other demersal species to possess lower (HSI) values than free-swimming species. Sherman (1997) and Sherman & Spieler (1998) examined yellow stingray gill vasculature, which further supported several structural differences in anatomy between urolophids and other elasmobranchs previously reported by Donald (1988). Olson *et al* (2000) correlated batoid sedentary behavior to the observed spontaneous contractions of isolated blood vessels in yellow stingrays. Sulikowski and Maginniss (2001) examined the effects of salt-water dilution on the body fluid regulation of *U. jamaicensis*. Walker and Sherman (2001) described the gross brain morphology of yellow stingrays and provided comparisons with additional batoids.

Lovejoy (1996) performed an extensive study on myliobatoid systematics and recognized the Potamotrygonidae (freshwater stingrays) to be phylogenetically more related to the Dasyatidae rather than the previously considered Urolophidae (Brooks *et al*,

1981, Rosa, 1985 and Rosa *et al*, 1987). Seventeen urolophids (including *U. jamaicensis*) were among the species examined in Lovejoy's study, which provided additional information on the interrelationship of the family and supported the revision of *Urobatis* to the generic level (Miyake, 1988).

1.6.2 Reproduction and Development

Studies regarding reproductive biology primarily estimated timing of the mating season from limited observations of gravid females and neonate presence (Bigelow & Schroeder, 1953 and Yañez-Arancibia & Amezcua-Linares, 1979). Mating behavior was observed in Belize, which demonstrated male copulatory biting and confirmed the venter-to-venter positioning (Young, 1993). An earlier note by Dugger (1987) provided excellent photographs and mentions "coupling is brief" and mating can involve multiple males with a single female. Descriptions of embryonic development have been limited for *U. jamaicensis* (Garmin, 1885, Bigelow and Schroeder, 1953, LaMarca, 1961); emphasizing elongated external gill filaments, differing morphometrics of the disk in comparison to adult specimens and a unique embryonic structure (spiracular fold). LaMarca (1963) further suggested the embryonic spiracular fold (pre-natal structure observed only in amphi-American urolophids) might function to guide trophonemata into the spiracle and potentially assist in fetal attainment of nutritive histotroph (uterine milk). LaMarca (1964) later described the functional anatomy of the clasper and clasper gland, dismissing any other position than venter to venter during copulation, due to flexion and clasper length. Several female reproductive structures that have received further attention are the epigonal gland (Cavanaugh & Hamlett, 1995), uterus and shell (oviducal) gland (Jezior & Hamlett, 1994 and Hamlett *et al*, 1996) and the ovary (Hamlett *et al*, 1999).

1.6.3 Feeding & Ecology

The diet and feeding habits of *U. jamaicensis* were mentioned by Bigelow and Schroeder (1953) and studied more thoroughly in Mexico by Yañez-Arancibia and Amezcua-Linares (1979) and locally in South Florida by Quinn (1996). These studies determined the importance of polychaetes and small crustaceans in the diet of yellow stingrays. The Yañez-Arancibia and Amezcua-Linares (1979) study took place within a seagrass dominated lagoon system, and examined the stomach contents of (16) adult animals. During the dry season polychaetes and bivalves were abundant in stomach contents, whereas polychaetes and crustaceans were more frequent during the rainy season. Quinn (1996) analyzed the stomach contents of (31) animals; polychaetes dominated both numerically (35.2%) and by volume (35.6%). There was also a seasonally significant difference for polychaetes, which were consumed in higher quantities during the spring (March/April) and less during the fall (October/November). This may be a result of fewer polychaetes occurring in the sampled habitat or the rays spending less time foraging in the sediment. There was no statistical difference for prey items between genders (Quinn, 1996).

With the exception of the Yañez-Arancibia and Amezcua-Linares (1979) study in the Gulf of Mexico, the only other study to address basic ecology of *U. jamaicensis* has been Sulikowski (1996). His unpublished thesis examined the growth, population density and age determination of the yellow stingray in Broward County, Florida with comments on diel and seasonal patterns of distribution. The maximum age determined for a 392 mm female was 8 years with rapid growth evident from vertebral banding patterns (33% of total growth in the first year). Sulikowski (1996) also reported early sexual maturation

by two years of age and 200 mm TL, supporting the earlier work by Yañez-Arancibia and Amezcua-Linares (1979).

2.0 Statement of Purpose

To address the ecology and associated behavior of animals in their natural environment, it is necessary to establish their basic movement patterns (Tester & Siniff, 1965). In a study on coral trout, *Plectropomus leopardus,* Zeller (1997) stated, "the patterns of movement and space use by an individual can be considered one of the most fundamental demographic parameters which influence ecological patterns of populations, communities and species". The extent of social interactions between animals is determined by space-related behavior, which can affect species density, reproductive activity and food availability. In addition, determining the temporal and spatial patterns of activity provides insight on habitat use, required to identify resource selection and associated behaviors (Winter & Ross, 1982, Reese, 1978 and Harris *et al*, 1990).

Thus, determining the activity patterns, space utilization and distribution of yellow stingrays is the first step in comprehending the existing population dynamics and is, therefore, the central objective of my research. Daily patterns of movement can be affected by various environmental factors (e.g. weather and temperature) and fish may alter their habitat use throughout the year on a diel, tidal, lunar or seasonal basis (Tester & Siniff, 1965 and Reese, 1978). During this study, ultrasonic telemetry was used to facilitate the tracking of diel movements, and visual surveys were conducted to ascertain the seasonal distribution of *U. jamaicensis* in Broward County, Florida (25° N Latitude and 80° W Longitude).

2.1 Telemetry Review

Early research efforts on marine vertebrates were restricted by the inability to study highly mobile and cryptic species in the marine environment (Nelson, 1978, M^{c}Kibben & Nelson, 1986 and Gruber *et al*, 1988). Although laboratory studies have yielded valuable insight, they are often "incomplete until the findings have been verified under natural conditions with unrestrained animals" (Stasko & Pincock, 1977). The development of ultrasonic telemetry has enabled researchers to maintain contact with individual animals and assess various biological and environmental factors associated with observed movements (Ireland & Kanwisher, 1978). Telemetry tracking has become a standard technique for monitoring the ecology and conservation of various marine organisms.

2.1.1 Telemetry Equipment

The most basic and commonly used form of telemetry is manual tracking with simple pingers or acoustic beacon transmitters (Nelson, 1997). The advantages are simplicity, duration and low cost; however the information gathered is limited to positional data of the telemetered animal. Essential tracking equipment consists of a transmitter, hydrophone and a receiver with headphones. The transmitter or telemetry tag sends a low frequency signal (usually, 30-80 kHz), which is detected and monitored by a submerged, hand-held hydrophone. The receiver converts the signal into audible sounds and enables the tracker to determine a location from direction and signal strength. A detailed description of the specific telemetry equipment utilized in this project is provided in section (3.2.4).

Numerous factors can influence the specific design and assembly of the transmitter package. The duration of the study (short-term vs. long-term), size and mobility of the animal, environmental conditions, and study location are all circumstances of relative importance. The tag size, range, operating frequency, and battery life are interdependent and determine the type of transmitter most suitable for individual tracking studies. Frequencies are inversely proportional to acoustic tag diameter, therefore the smaller the transmitter the higher the frequency (Priede, 1986). Higher frequencies are subject to increased interference associated with boat motors and wave attenuation and are absorbed more easily by suspended solids and underwater structures (e.g. coral reefs) (Wolcott, 1995). Lower frequencies have greater range capabilities, but require larger sized transmitters to produce the longer wavelengths (Kanwisher *et al*, 1974). Increased length and diameter of acoustic tags also supply additional storage for larger, longer-lived batteries or multi-channel sensors (e.g. temperature measurement). The choice of frequency results in a compromise between large transmitters with ranges of several kilometers and small transmitters with ranges up to 1 kilometer (Hawkins & Urquhart, 1983). Manufacturers are continually designing new tags to reduce size while maintaining effective ranges and many improvements in tag design have been made during the course of this study.

Regardless of the intended study goals, transmitter selection is inevitably limited by study animal size. Standard protocols normally restrict transmitter size to less than 2% of the total body weight of experimental animals to minimize any potential negative influence on normal behavior, due to weight constraints (Stasko & Pincock, 1977 and Hawkins & Urquhart, 1983). However, a recent study has suggested that a larger ratio of

10-12% is acceptable without interfering with the normal behaviors and activities of telemetered fish (Brown *et al*, 1999).

2.1.2 Tag Application

The method of attachment in short-term studies, should involve a limited amount of trauma (Nelson, 1997). Self-ingestion or force-feeding of tags is considered the least traumatic application, however the size of the transmitter compared to the rays stomach would likely interfere with their feeding behavior (Adams *et al*, 1998). Surgical implantation of tags into the body cavity is more suitable for longer-term studies and involves additional trauma and periods of recovery (M^{c}Kibben & Nelson, 1986 and Nelson, 1997). Externally attached transmitters may impede the animal, either by direct interference with locomotion, increased drag resistance and snagging, or increased weight (Hawkins & Urquhart, 1983). However, these negative effects associated with external attachment are considered less crucial for demersal species and therefore, should not modify animal behavior, particularly during short-term studies (Stasko & Pincock, 1977 and Thorstad *et al*, 2001).

2.2 Batoid Tracking

Many of the previous studies on batoids have been conducted in bays where much of the habitat consists of seagrasses and shallow mudflats and where there is considerable influence from tidal conditions. Tidally influenced movements are considered to occur due to the expansion of available foraging habitat during high tide (Babel, 1967, Gilliam & Sullivan, 1993 and Ackerman *et al*, 2000) or passive transport, where batoid morphology (dorso-ventrally flattened) is hypothesized to benefit from the use of tidal currents in order to decrease energy expenditure while swimming (Teaf, 1980 and

Blaylock, 1992). Tracking studies have been limited to relatively few species of batoids and have typically been preliminary studies with small sample sizes (Appendix C).

Dasyatis sabina (Atlantic stingray) traveled with tidal flow 90% of the time in Apalachee Bay, Florida, however, the use of balloon float tags to observe movements may have required this behavior due to excessive drag (Teaf, 1980). *Rhinoptera bonasus* (cownose ray) also demonstrated a tendency to move in the direction of tidal currents in Chesapeake Bay, Virginia, but track durations were not long enough to evaluate diel activities (Blaylock, 1988, 1992). Silliman and Gruber (1999) reported tidally influenced foraging patterns for *Aetobatus narinari* (spotted eagle ray) at Bimini in the Bahamas. Eagle rays refuged during incoming low tide and commuted to and from foraging sites during the remaining portions of the tidal cycle. Telemetry studies on batoids from areas with apparent tidal influence still need to address space use patterns and activity rates during high tide when observed movements are not oriented to the direction of tidal flow.

Most batoid telemetry studies have evidenced a clear diel periodicity to changes in behavior with increased patterns of activity during crepuscular and nocturnal phases; movements appear to be stimulated by decreasing levels of light. The diurnal phase (photophase) often consists of various periods of inactivity (refuging) or reduced rates of movement.

Dubsky (1974) studied the movement patterns of a large male bat ray, *Myliobatis californica*, which predominantly used shallow areas of the inner bay in Morro Bay, California. Activity rates depicted a slight increase during nocturnal movements with no significant correlation to the tidal phase. Dubsky (1974) also tracked a single shovelnose guitarfish, *Rhinobatus productus*, which exhibited higher levels of activity at night and

during low tide. Pacific electric rays, *Torpedo californica*, displayed strictly nocturnal movements in relation to feeding activities, in contrast to performing ambush attacks from the substrate during the day (Bray & Hixon, 1978 and Lowe *et al*, 1989). A more recent study on *M. californica* potentially demonstrated behavioral thermoregulation in Tomales Bay, California. The rays exhibited distinct diel patterns of movement, moving toward the shallow (warm) inner bay to forage diurnally and then moving to the deeper (cooler) outer bay at night, regardless of tidal direction (Hopkins & Cech, 1994 and Matern *et al*, 2000). Yano *et al* (2000) tracked the movements of manta rays, *Manta birostris*, equipped with depth sensing transmitters at the Yaeyama Islands, Okinawa, Japan. Diurnal movements were typically shallow (surface to 50m) and close to shore, while nocturnal movements were offshore in water 100-200 m deep. Nocturnal rates of movement and activity spaces were determined to be significantly larger for Hawaiian stingrays, *Dasyatis lata*, in Kaneohe Bay, Hawaii (Cartamil *et al*, 2003). The diurnal phase was characterized by periods of little activity, and there was no evidence of site attachment to daytime refuge areas or tidal influence.

2.3 Benthic Elasmobranch Telemetry

Several other elasmobranch species with a similar benthic or demersal lifestyle have been acoustically tracked. Dubsky (1974) tracked (3) horn sharks, *Heterodontus francisci* and (6) leopard sharks, *Triakis semifasciata* (9.25 h – 24.25 h), which all displayed nocturnal increases in activity. Standora & Nelson (1977) tracked (9) Pacific angel sharks, *Squatina californica*, off Catalina Island, California for periods of 13-25 hours. The angel sharks primarily exhibited nocturnal movements with peak activity rates occurring throughout the night and during crepuscular periods. The short-term

tracking of this study found *S. californica* appears to confine their movements to a distinct, limited area. A separate study on the long-term, intermittent movements of (11) *S. californica* (14 - 90 days) also displayed strictly nocturnal movements; however, several individuals indicated more extensive movements around the entire Catalina Island (Pittenger, 1984). The short-term movements of *Ginglymostoma cirratum* (nurse shark) at Big Pine Key, Florida were reported to be random with no correlation to tidal conditions (Carrier *et al*, 1985). The Pacific horn shark, *Heterodontus francisci*, demonstrated repeated diel patterns of nocturnal activity often remaining at and returning to a single location during the diurnal phase (Strong, 1989). Ackerman *et al* (2000) reported that *Triakis semifasciata* (leopard shark) movements in Tomales Bay were correlated to the direction of tidal flow, regardless of time of day. Leopard sharks used the shallow inner portions of the bay to forage during high tide and were located at the outer bay during low tide.

2.4 Batoid Seasonal Distribution

Seasonal distribution is commonly monitored through tag and recapture studies to establish individual movements or by repeated sampling at the population level for species presence (Bearden, 1959, Babel, 1967, M^{c}Eachran & Musick, 1975, Edwards, 1980, Pittenger, 1984, Schmid, 1984, Carrier, 1985, Talent, 1985, Smith & Merriner, 1987, Rudloe, 1989, Capapé & Zaouali, 1994 and Gray *et al*, 1997). Although conventional tagging studies generally experience low recapture rates, they still have been useful for determining long-term movement patterns and the extent of site fidelity. In contrast to the individual detail associated with tag-recapture studies, large-scale sampling for presence/absence is often used to characterize the seasonal dynamics of

population structure and distribution. The most widely used methods have consisted of bottom trawl sampling, gill netting and beach seining, all of which may provide simultaneous data collection of both long-term movements and site fidelity. Drawbacks for these techniques involving nets often include sampling bias, predominantly associated with mesh sizes too large to collect smaller individuals (Smith & Merriner, 1987, Gray *et al*, 1997 and Snelson *et al*, 1989). Most studies have described the seasonal distribution of batoids in relation to changes in temperature or salinity; variables which induce localized inshore/offshore dispersal or larger-scale, north/south migrations (Appendix D).

Seasonal occurrence of some species may involve extensive migrations while other species remain permanent residents at a location throughout the year. Dependent on local habitat conditions allopatric populations of the same species may display different behavioral patterns. *Dasyatis sabina* was considered a permanent resident in the Indian River Lagoon System (Schmid, 1984 and Snelson *et al*, 1988), while in the Gulf of Mexico this species disperses offshore during the winter associated with an abrupt decrease in temperature (Sage *et al*, 1972 and Funicelli, 1975). Populations occurring in temperate regions can experience greater variation in environmental conditions, whereas, warmer climates are associated with increased stability (Thorson, 1983). There may also be evidence for combined effects of temperature and salinity functioning as a precursor to environmental change (temperature) and physiological acclimation during a shift in habitat (salinity). While making annual migrations to and from coastal Atlantic waters, *Rhinoptera bonasus*, move along the eastern shoreline of the Chesapeake Bay, where higher salinities may allow a gradual adjustment for osmoregulation (Schwartz, 1965 and Smith & Merriner, 1987).

Temperature and salinity can also influence diel activity patterns and local distribution of year round populations. In the Indian River Lagoon system distribution of *D. say* (bluntnose stingray) appear to be influenced primarily by the salinity regime (Snelson *et al*, 1989), whereas, *D. sabina* altered activities between deep channels and shoals during the winter months associated with temperature fluctuations across a 15° C threshold (Snelson *et al*, 1988).

2.5 Urolophid Movements and Seasonal Distribution

The extent and capabilities of urolophid movement has undergone some investigation through conventional tagging and recapture studies. Babel (1967) determined *Urobatis halleri* (round stingray) off California to be non-migratory, either remaining at or returning to the same location. His recapture data had a maximum distance traveled of 4.75 miles in 208 days at liberty, with the most abrupt movement of 2 miles within 4 days (Babel, 1967). Data from 39 recaptured animals also supported that movements became more extensive with an increase in stingray size (Babel, 1967). In an earlier study by Russell (1955), 61 *U. halleri* were recaptured of 482-tagged individuals, with slightly more extensive movements reported. The stingrays were at liberty between 4 to 14 months and traveled a variety of distances before recapture (32 stingrays were recaptured in the same area, 18 stingrays moved less than 15 miles and 11 were recaptured over 15 miles from their point of release). However, Russell (1955) also noted that *U. halleri* tended to return to the same general location each summer and additional studies on other batoids have also observed seasonal migration patterns (Schwartz & Dahlberg, 1978 and Gray *et al*, 1997). Edwards (1980) conducted a population study of *Urolophus paucimaculatus* in Port Phillip Bay, Australia and

observed biomass 2-3 times higher in the summer and fall (December & March) than in the winter (August), with emigration out of the bay likely due to decreasing water temperatures.

The extent to which reproduction plays a role in seasonal distribution has been mentioned in previous studies (Strong, 1989), but requires further investigation. Yañez-Arancibia and Amezcua-Linares (1979) indicated the Terminos Lagoon was primarily used for breeding activity and as a nursery for young *U. jamaicensis*. A total of 56 adults were observed, of which 46 were female (numerous gestating), suggesting temporary gender segregation as females emigrate inshore in preparation for parturition. Talent (1985) collected 48 round stingrays (*U. halleri*) in Elkhorn Slough and determined that the population appeared migratory; frequent captures were made in the winter months, but rarely during the remaining parts of the year. Elkhorn Slough was not considered to serve as a nursery ground as nearly all observations involved adult males with no occurrence of gestating females or juveniles (Herald *et al*, 1960 and Talent, 1985).

A 13-month tagging study of 108 yellow stingrays was conducted in South Florida (August 1992 – September 1993). A total of 30 sampling trips were performed, yet the study experienced a 0% recovery rate (Sulikowski, 1996). The benthic hardbottom communities of South Florida prohibited trawling, therefore the inability to cover large areas and the need for divers to physically search out individual stingrays most likely led to the failure in relocating study animals. Nonetheless the initial capture data indicated a possible seasonal movement with an average depth of >5 m and water temperature of 24ºC during the winter and early spring (n = 33), and <5 m with temperatures between 27 - 30ºC during the summer and fall (n = 64).

Platell *et al* (1998) studied the densities and feeding patterns of four urolophids (*Urolophus lobatus*, *U. paucimaculatus*, *Trygonoptera personata* and *T. mucosa*) in Southwestern Australia. The density for each of the stingaree species differed between shallow and deep waters and /or between regions (latitude). Neither the size composition or sex ratio for any of the four species studied showed significant differences between sites and a range from neonates to sexually mature individuals of each species was found at all sites where that particular species was common. No evidence for seasonal variation was reported and the authors concluded that temperature preferences and resource partitioning (variation in major prey items) determine occurrence and distribution of each species.

3.0 Materials & Methodology

3.1 Study Site

Ultrasonic telemetry was conducted to track diel movements, and stationary point counts were used to determine population seasonal distribution of yellow stingrays. Data collection was conducted in the coastal waters of Broward County, located on the east coast of South Florida, U.S.A. (Figure 2). Telemetry tracking was conducted off the coast of John U. Lloyd State Park, situated just south of Fort Lauderdale on the southern margin of Port Everglades Inlet (Figure 3); the area where a previous ecological study on *U. jamaicensis* had been conducted (Sulikowski, 1996). The reefs of the study site are submerged or drowned Holocene barrier reefs that continue to provide suitable substrate for the settlement of benthic fauna. These relict barrier reefs are often referred to as ridges or terraces since active accretion terminated approximately 7000 years ago

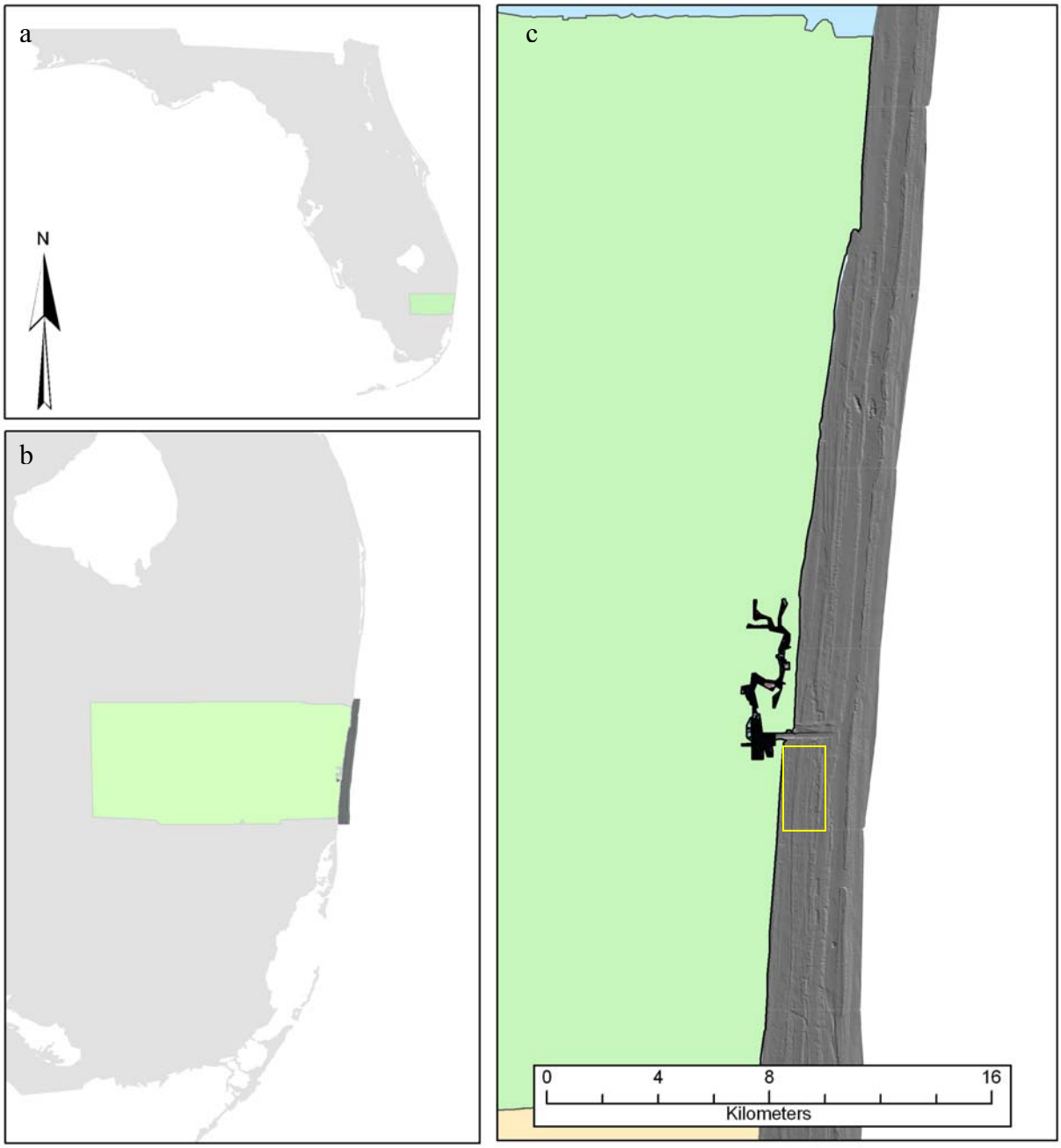


Figure 2. **Study site**: **a**. State of Florida with Broward County highlighted in green. **b.** Enlarged image of Broward County with coastline highlighted in gray. **c**. Close up of Broward County coastline demonstrating the bottom topography from LADS imagery. Area outlined in yellow indicates the region where all telemetry tracking was conducted.

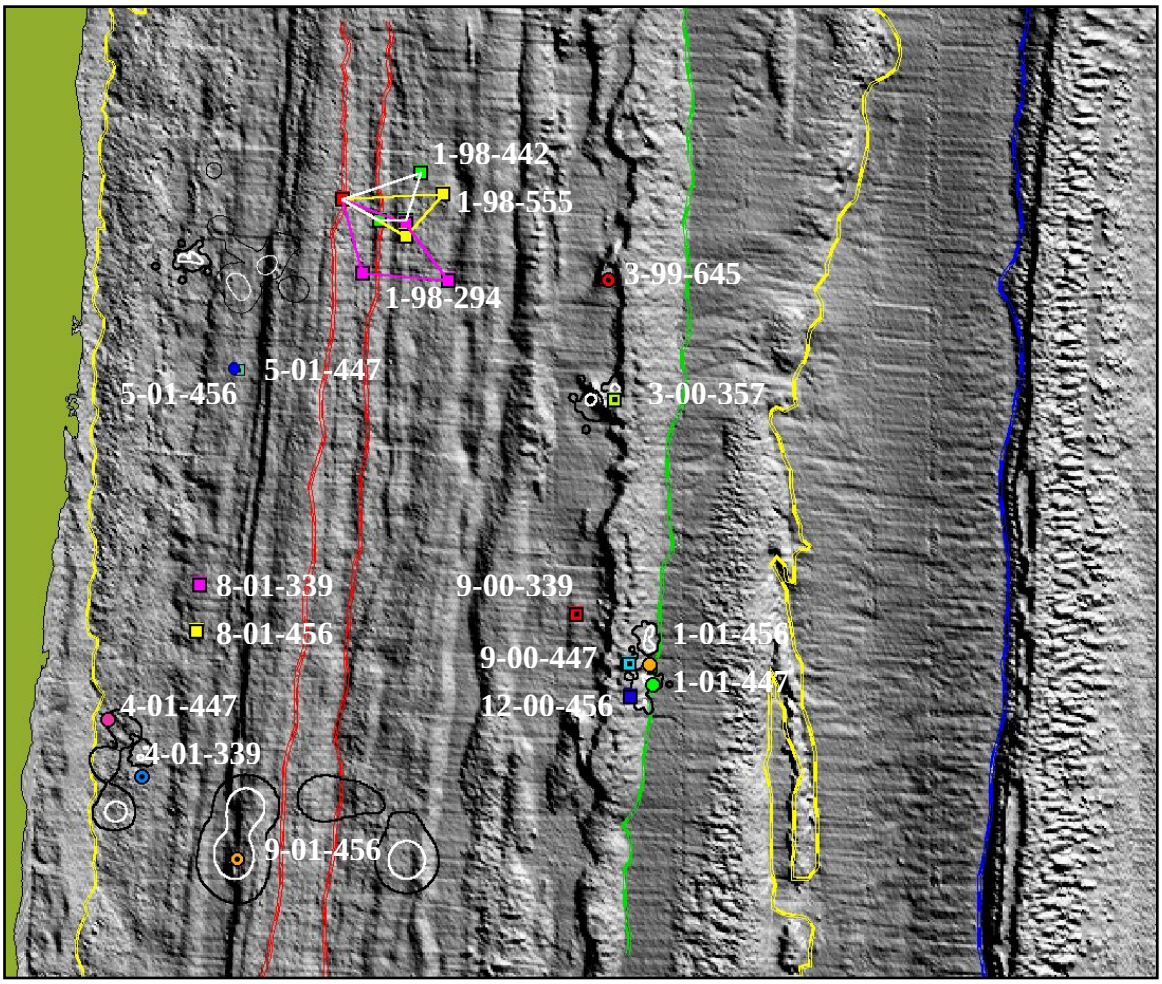


Figure 3. **Telemetry study site**: Total capture sites for 17 stingrays offshore of John U. Lloyd State Park. LADS image: yellow lines indicate the western edge of the 1st reef and the eastern edge of the second reef. Red lines indicate the boundary zone between 1st reef (eastern edge) and the 2nd reef (western edge). The green line outlines a prominent edge, bordered by sand and rubble within the 2nd reef complex and the blue line indicates the western edge of the 3rd reef.

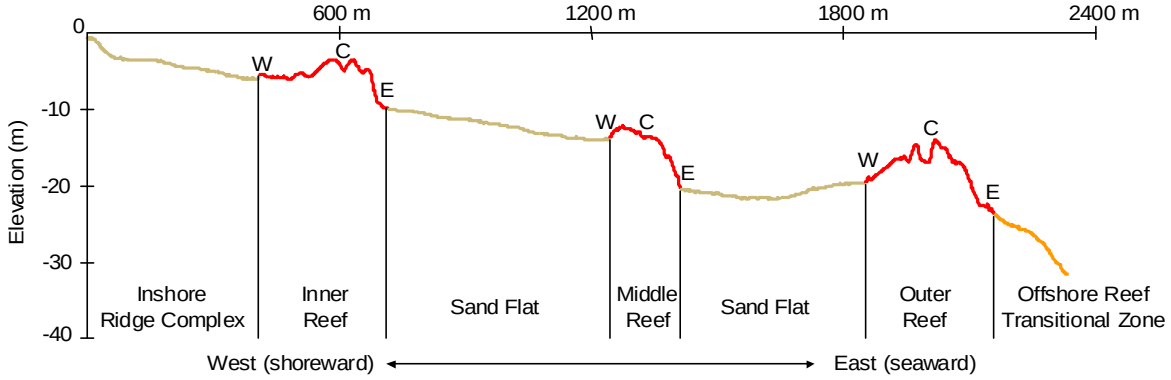


Figure 4. Broward County Reef Profile demonstrating the three main reef tracts, established from bathymetry data and the sandy transitional zones between reefs

(Lighty *et al*, 1978 and Goldberg, 1973). The three main ridges are linear, running parallel to shore in progressively deeper water with areas of sand and patchy rubble in between and are locally referred to as the 1st, 2nd and 3rd reefs with the 1st reef tract the most inshore (Figure 4). Gorgonians, sponges, moderate sized coral colonies and macro algae variously dominate the region (Jaap, 1984). For ease of discussion all future reference to reef or reef community will be in relation to their offshore location from the beach (e.g. 1st, 2nd or 3rd reef tract).

All specimens for telemetry tracking were collected from hard bottom areas within the first and second reef communities in water 5-15 meters deep. In addition to tracking, seasonal distribution data was collected from stationary fish surveys from other studies conducted throughout the entire length of Broward County. Point counts (Bohnsack & Bannerot, 1986) were performed along different zones across all three main reef tracts (Ferro, 2003), established inshore sites (Baron *et al*, 2004), annual Broward County monitoring sites (Gilliam *et al*, 2002) and adjacent areas to artificial reefs (Arena *et al*, submitted).

3.2 Telemetry Study Design

Ultrasonic telemetry was conducted to track the short-term movements of mature yellow stingrays to determine diel activity patterns and space utilization. A total of 17 animals were tracked during the telemetry study (January 1998 to September 2001). Stingrays were continuously tracked for periods ranging from 8-30 hours with animal locations marked at 15-30 minute intervals. One or two animals were tracked during each telemetry session and attempts were made to continuously monitor the movements of all rays for a minimum of 24 hours. However, data is only presented for animals with

movements determined for a full diel cycle (n = 8) to adequately compare activity rates between diurnal (photophase) and nocturnal (scotophase) periods. Following termination of all tracking sessions, efforts to recapture each individual were made for the retrieval of transmitters.

3.2.1 Capture of Stingrays

SCUBA divers equipped with hand nets collected the study animals and marked the capture site with a weighted dive flag. Once a stingray was located and captured, divers immediately surfaced and relayed the animal to boat personnel. The initial location was designated as the capture site and a Differential Global Positioning System (DGPS) or a Wide Area Augmentation System (WAAS) position was recorded. Once onboard the tracking vessel, all rays were affixed with a telemetry tag (see 3.2.2 below). Tracking either commenced two hours later the same day for animals captured during morning hours or was initiated the following morning for animals captured in the late afternoon.

3.2.2 Tagging Procedure

Limiting the period of capture and attachment of transmitter (sutured externally), rather than surgical implantation and prolonged confinement, was selected as the technique for the current project design. Rays were anesthetized in a bath of 0.6 g (MS-222) Tricaine Methanesulphonate (Finquel; Redmond, WA)/5 liters seawater (32ppt) until spiracular ventilation ceased; normally this required 2-4 minutes. Rays were then placed on a sizing table, where measurements for total length (TL), disc length (DL) and disc width (DW) were obtained and the gender recorded. As a safety precaution, a 4-lb bag of lead pellets (soft dive weight) was laid across the caudal fin to minimize

movement and cover the caudal spine. Transmitters were externally attached to the epaxial musculature with (3.0 metric) sterilized monofilament sutures (Ethicon, Inc., Somerville, NJ). The horizontal mattress suturing technique (J. Herrington D.V.M., personal communication) was performed on both ends of the transmitter to secure the telemetry tag to the dorsum (Figure 5). The entire tagging procedure (including sedation) from time of capture until point of release lasted 7-12 minutes.

Figure 5. Tagged Ray: post-surgery photo of stingray #4 (3-99-645) from a preliminary track on 03/15/99 with ITS-95 (Sonotronics, Tucson, AZ) pinger tag shown externally attached.

Preliminary work in holding tanks demonstrated suture durability of approximately two weeks. This was adequate for 24 to 48 hours of tracking and to handle any possible delays in tag retrieval due to weather conditions. Immediately following surgery all rays were returned to the site of capture and monitored by divers for several minutes to observe their recovery from anesthesia. Normal activity of captive stingrays resumed within several minutes of their return to the holding tank during practice surgeries. Although the effects of capture, restraint and tagging can not be discounted, it is noteworthy that three out of four experimental stingrays in captivity readily consumed hand fed shrimp immediately following the surgical procedure.

3.2.3 Telemetry Equipment

All ultrasonic transmitters were of the simple pinger type (IT95-2 coded tag, Sonotronics, Inc. Tucson, Arizona), which provide information on location only. The transmitters operated at 75-76 kHz, with varying pulse intervals allowing individual tags to be identified on the same working frequency. For example, tag #123, would beep once, pause, beep twice, pause, beep three times and pause again before repeating the cycle. This coding permitted the simultaneous tracking of multiple animals on the same frequency. The tags measured 50 x 14 mm, weighed 5.0 g in water and possessed a battery life of one year. All transmitters were turned off, by a small magnet switch attached to the end of the transmitter, and stored while not in use to conserve battery life. Only mature animals were used to ensure that transmitter weight did not unduly influence behavior.

a. b.

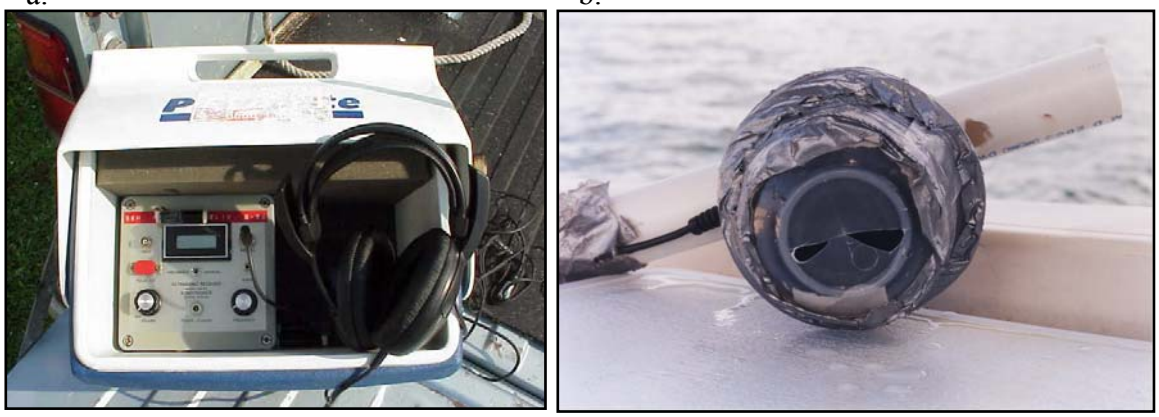


Figure 6. Telemetry equipment: **a. USR-5W** manual receiver with headphones and **b. DH-2** hydrophone shown with plastic faring. (Sonotronics, Tucson, AZ).

Transmitter signal output was monitored with a manual-tracking receiver (USR-5W, Sonotronics, Tucson, Arizona) and the identifying code was recognized while listening with headphones. The receiver was equipped with a directional DH-2 hydrophone (Sonotronics, Tucson, Arizona) and mounted on an 8´x 2´´ PVC shaft. The

USR-5W receiver has a sensitivity of 1.0 microvolts for 30dB and the DH-2 hydrophone a sensitivity of –84 dBV ref 1 microbar, according to the manufacturer, and a beam width of ± 6 degrees at half power points. The total system (Figure 6) offers a reported maximum range of 1-km under ideal conditions, however the observed working range in this study was considerably less.

An effective range of 350 – 500 m was estimated from preliminary tests of signal strength on stationary transmitters. Preliminary tracking noted high levels of ambient noise, causing considerable interference of signal reception, which was most likely due to excessive boating traffic and benthic crustacea (e.g. snapping shrimp). Port Everglades is the most active seaport on the eastern seaboard of the U.S. and Fort Lauderdale, considered by many to be the yachting capital of the world, experiences heavy boating traffic daily. In addition to the boating traffic, the close proximity of the study site to the arriving and departing air traffic from the Fort Lauderdale/Hollywood International Airport added further noise interference.

3.2.4 Tracking Protocol

Two to three person crews alternated on 6-hour shifts for each 24-hour tracking period. A driver operated the tracking vessel while the remaining crewmembers performed the tracking and data recording following a modified version of Holland *et al* (1985). All location data was recorded every 15-45 minute. During the tracking interval the telemetered rays were tracked until the tracking vessel was positioned directly over the transmitter and an omni-directional signal was determined (ground zero) (Pittenger, 1984, Strong, 1989 and Nelson, 1997). DGPS or WAAS corrected coordinates (WGS-84) and depth measurements were recorded for each ground zero position.

3.2.5 Direct Observations During Tracking

Periodic direct observations while free diving were performed to record the activity, position and condition of the stingrays under investigation. The ability to obtain precise locations becomes increasingly more important for demersal species, which may remain situated in a single location across several tracking intervals, are involved in telemetry studies (Strong, 1989). A weighted buoy was deployed in the vicinity of the recorded position and used to expedite the transition (back and forth) between simultaneously tracked animals. The tracker would also note the proximity and bearing from the tag to the buoy to determine occurrence of small-scale movements, as well as, to determine the onset of larger movements. The inherent accuracy limitations of the GPS equipment can indicate small movements between consecutive recorded positions when none actually occur (Siniff & Tester, 1965). Recent accuracy tests have recommended the use of DGPS (for differential correction) to reduce positional estimate error to less than 3 m (Collazo & Epperly, 1995).

3.2.6 Blind Accuracy Tests

To evaluate potential tracker-induced positional error involved during tracking, the methods of Strong (1989) were conducted. Blind accuracy tests were performed to assess position location certainty and establish the trackers ability to successfully achieve a ground zero position fix (e.g. placing the boat directly over the transmitter). A series of ten preliminary blindfolded tracking runs were conducted with a transmitter placed at 5 m of depth. Tracking was initiated at distances greater than 200 m from the transmitter and a weighted buoy was dropped once ground zero was determined. Divers measured the

distances from weight to transmitter with PVC survey tape to determine the range of positional accuracy.

3.2.7 Schedule

The tracking regime consisted of 1-2 animals monitored per tracking period for a full diel cycle. All tracking sessions were scheduled for periods of 24 to 30 hours, however, changing weather conditions often required postponement of tracking until thunderstorms and seas subsided and the conditions became safe for small craft operation. Preliminary tracks were conducted in January 1998, which consisted of the intermittent tracking of three stingrays to determine short-term movements and areal occupation (overall area used). The remaining 14 telemetry trackings were conducted during March 1999, March 2000, September 2000 (2 animals), December 2000, January 2001 (2 animals), April 2001 (2 animals), May 2001 (2 animals), August 2001 (2 animals) and September 2001. Preliminary tracking and captive observations were conducted to examine any notably adverse effects of the tagging procedure on stingrays prior to initiating the diel tracking study.

3.3 Seasonal Distribution Study Design

Direct observations via SCUBA, extending throughout Broward County, were obtained during all months of the year (January, 1998 – December 2003) to estimate the seasonal distribution of the local yellow stingray population. Data from four separate studies on reef fish assemblages off Broward County were pooled together to document the presence and abundance of yellow stingrays. These studies used a modified point count method (stationary visual census) (Bohnsack & Bannerot, 1986). Each point count was conducted within an imaginary 15 m cylinder, which was established by laying out a

weighted 7.5 m line. Point count data was analyzed for the presence of animals within the first five minutes with information on the number of individuals and total size to the nearest (cm) recorded. Additional presence was noted for individuals arriving after the first five minutes, during the time interval when abundance and size measurements were recorded (normally about 10 min) (Ferro, 2003).

A total of (940) counts were performed along all three reef tracts, with (617) counts from August 1998 to November 2002 from the Broward County fish assemblage project (Ferro, 2003) and an additional 93 counts obtained from natural reefs adjacent to shipwrecks (Arena *et al*, submitted). In June 2001, (101) counts were conducted for a nearshore fish assemblage study (Baron, 2002) with an additional (35) follow up counts in August 2003 (Baron *et al*, 2004 and Jordan & Spieler, submitted). Finally, an ongoing annual monitoring program has produced (94) counts to date from numerous permanent stations throughout Broward County and adjacent areas (Gilliam *et al*, 2002). In addition to the foregoing studies, personal observational data was collected outside of the point counts and during other studies in Broward County. Data from all these sources were combined to examine the population structure of yellow stingrays.

3.4 Population Structure

Sex ratio and size-class proportions were compared to determine frequency of occurrence and identify any existing gender segregation and ontogenetic partitioning (age class segregation) within the *U. jamaicensis* population structure. Research data from the Broward County studies (when gender was identified), combined with additional personal observations were used to examine seasonal or monthly population structure variation within each of the three reef tracts. Gender was confirmed by the presence or

absence of claspers (male copulatory appendages) for each individual. Total length estimates were recorded to the nearest (cm) and grouped into size classes for ease of data management.

3.5 Reproduction

Reproduction observations consisted of field identified gravid females (noticeable convex distortion of the dorsal region) and was grouped into gestating (G) or non-gestating (N) categories. Data collection followed the same format as population structure to examine the seasonal and monthly occurrence of gestating female stingrays on all three reef tracts.

3.6 Data Analysis

Arcview GIS (v. 3.2) (ESRI®, San Diego, CA) with Spatial Analyst and the Animal Movement Analyst Extension (AMAE, USGS, Glacier Bay, AK) were used to calculate circular statistics, distance and space utilization measurements and for graphical representation of telemetry movement data (Hooge & Eichenlaub, 1997). STATISTICA™ software (v. 6.0) (StatSoft®, Tulsa, OK) was used to perform all other statistical analyses. Standard tests for equal variance (Levine test) and normality (Kolmogorov-Smirnoff test and Shapiro-Wilk test) were conducted to determine if the data met the assumptions required of parametric analysis (Sokal & Rohlf, 1995, Zar, 1999). All data were non-normally distributed and transformation of the data was unsuccessful in normalization, therefore non-parametric tests were used for all statistical analyses. A p-value ≤ 0.05 was accepted as a significant difference.

Comparisons of the distances moved, activity rates and utilization distributions were tested for significant differences between daytime versus night. Daytime and

nighttime activities were partitioned by local sunrise and sunset data (U.S. Naval Observatory Astronomical Applications Department). Daytime and nighttime distances per tracking interval (movelengths) were pooled for the eight individuals tracked for a full diel cycle and a Mann-Whitney *U*-test (MW) was performed on the non-normally distributed data. Movelength data was also analyzed for crepuscular movements (established as 1-hr before and after sunrise and sunset) and compared with both diurnal and nocturnal distances traveled with the MW test. Activity rates or hourly rate of movement (ROM) was determined for the pooled distances traveled between each tracking interval per hour and a MW test was used to compare activity for day vs. night.

The Kernel home range estimator in AMAE was used to measure the utilization distributions (UD) for the 95% (total area) and 50% (core area) activity spaces (Worton, 1987). The Kernel method is a probability density estimator, which fundamentally describes the amount of time an animal spends within a concentrated area. Higher values are indicative of regions where more locations are positioned (greater density), which enables the kernel method to provide the most accurate estimates of the size and shape of the true UD (Seaman & Powell, 1996). Kernel density estimation is valuable for analyzing data that is multimodal and non-normally distributed, which is typical of telemetry data (Seaman & Powell, 1996). In kernel analyses the *h* smoothing parameter was selected by least squares cross validation (LSCV). Previous studies have indicated that cross-validated fixed kernel estimation produced the most accurate density estimations (Worton, 1989, Seaman & Powell, 1996, Taulman & Seaman, 2000 and Hooge *et al*, 2000). The Kernel density estimator in AMAE generates graphical probability contour plots and furnishes values for the area utilized. The 95% and 50%

distributions for eight individual stingrays were calculated after the data was divided into four 6h periods (n = 32) and the pooled daytime and nighttime areas were tested for significant differences with a MW test.

Indices of site attachment were used to determine short-term direction of movements and the extent of diel influence on the patterns of areal distribution (Cooper, 1978 and Morrissey & Gruber, 1993a). Linearity indices (LI) were run with AMAE to determine the level of site fixity demonstrated for each animal tracked. Site fixity implies the consistent re-use of a specific area, whereas site fidelity requires a longer-term repeatability of space use. The LI consists of measuring the distance between movement endpoints (start and finish) and dividing by the total distance traveled during the entire track (equation 1.0).

$$\mathbf{LI = L_n - L_1 / L_t}$$

Where, L_n = final position, L_1 = start position and L_t = total distance moved. A value equal to 1 represents total linearity or a straight line and values less than one indicate progressively confined movements as the value approaches zero (Morrissey & Gruber, 1993a). To establish overall directedness of movements, LI were performed for the total 24-h tracks. Diurnal and nocturnal LI were conducted on the individual 6-h shifts to determine if diel periodicity influenced the level of site fixity. A MW test was run to compare the individual 6-h diurnal and nocturnal linearity data for significant differences.

The site fidelity test (here designated site fixity test) is a randomization test implemented by the (AMAE) in the GIS environment. The test performs a Monte Carlo simulation for a user-defined number of random walks (RW) by recombining the turning angles (bearing) and preserving the sequential distances of observed movelengths (Hooge *et al*, 2000). The individual linearity (LI) and mean squared distance (MSD) values are

calculated for each random walk to generate the probability tables for determining the type of movement displayed (confined, random or dispersed). Similar Monte Carlo tests have been used for testing the habitat use of tiger sharks (*Galeocerdo cuvier*) in Western Australia (Heithaus *et al*, 2002).

The site fixity test was performed on all total 24-h tracks and compared the mean squared distance (MSD), a measure of dispersion from the center of activity (COA) and linearity measurements, directedness of movements, between the simulated tracks and the observed movements (Hooge *et al*, 2000). In order for an animal to demonstrate site fixity (confined movements), observed tracks should not have significantly high MSD or linearity values. A total of 1000 random walks were generated for each animal with graphical shapefiles and tabular values provided. The starting location of each RW was established by the initial tracking location for all simulations. The null hypothesis for each test was the observed tracks consisted of random movements. High MSD and linearity designates dispersed movements that are highly directional, high MSD with low to moderate linearity relates random movements without specific directionality and both low MSD and linearity values will determine confined movements representative of site fixity/fidelity. AMAE expresses the values as the percentage of simulated tracks with higher MSD values than the observed tracks, where values of 0.95 (95%) or more are significantly higher and demonstrate confined movements (P. Hooge, personal communication).

The Kruskal-Wallis test (KW) was used to compare population distribution for all analyses of point count data. Stingray abundance (# of individuals present/count) was designated as the dependent variable for all tests. Cases were selected individually for

each month to compare between reefs (n = 3) for a total of (12) tests. The same test was run with all months pooled into seasonal categories, spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February) for a total of (4) tests. Another KW test was run with cases selected for each individual reef to compare abundance between all months (n = 12) for a total of (3) tests. The same three tests were run for each individual reef with monthly values once again pooled into seasonal categories.

Additional data collected outside the designated point counts, as well as, personal observations from other studies to determine population structure were unequally sampled between reef location and months requiring the use of further non-parametric tests. The nominal scale data (female or male) was binomially distributed and tested for Goodness of Fit, where the population followed a 1:1 ratio and each observation had an equal probability of being a female (p = 0.5) or a male (q = 0.5). Frequency distributions were analyzed for expected versus observed ratios with the log-likelihood ratio test (G-test) and 1-degree of freedom on categorized data with larger sample sizes (n > 25) (Sokal & Rohlf, 1995 and Zar, 1999). The recommended adjustment was made (William's correction) to limit the occurrence of a type I error with a more conservative ratio calculation. Smaller sample sizes (n < 25) were tested for significance with a two-way binomial test to compare exact probabilities for observed counts where cumulative frequency probability values of (p < 0.05) were considered significantly different from a 1:1 ratio (Sokal & Rohlf, 1995 and Zar, 1999).

Size class was determined from total length measurements and divided into (9) different categories at 50 mm increments starting at <150 mm for smaller neonates.

Either a *G*-test or a binomial probability test was also used to compare size class between genders in accordance to the same sample size requirements as the sex ratio data. Preliminary observations are included for reproductive characteristics and a case is made for the potential influence on seasonal patterns of movement and distribution of yellow stingrays. The majority of gravid females were determined from field observations, which was limited to recognizing the reproductive status of individuals in later stages of gestation and thus underestimating the number of gravid females. Monthly and seasonal comparisons of gravid females, for all three reefs, were conducted in the same manner as the sex ratio data.

4.0 Results

4.1 Telemetry Study

Positional accuracy, as defined by the blind accuracy tests, was within 3 m of the tag ($n = 10$, $\overline{X} = 2.76$ m ± 0.310 SEM). Although small-scale movements can be masked within this range, the errors associated with boat movements and GPS accuracy are likely of a greater extent. Water conditions often made boat maneuverability difficult and the GPS equipment used (handheld WAAS or mounted DGPS/WAAS) are listed as accurate to within 3 m (95% of the time). Therefore, regardless of achieving ground zero positioning, recorded GPS coordinates may involve small additional errors that equal or surpass the 3 m range of tracker-induced error.

The short period of handling time during transmitter attachment and the initiation of tracking after a minimum of two hours post surgery presumably should not have created any behavioral artifact to the observed movements. Past research on the Pacific angel shark (*Squatina californica*) has indicated an initial stress related response to

capture and tagging with normal behavior resuming after a period of two hours (Standora & Nelson, 1977). Direct observations during daytime periods revealed all animals resting and generally buried in sand patches within the hardbottom community. Often the buried stingray was indiscernible from the substrate and only the tag situated above the sand was detectable (Figure 7). The presence of conspecifics was noted on several occasions (see results of individual tracks and movement descriptions, Appendix E).

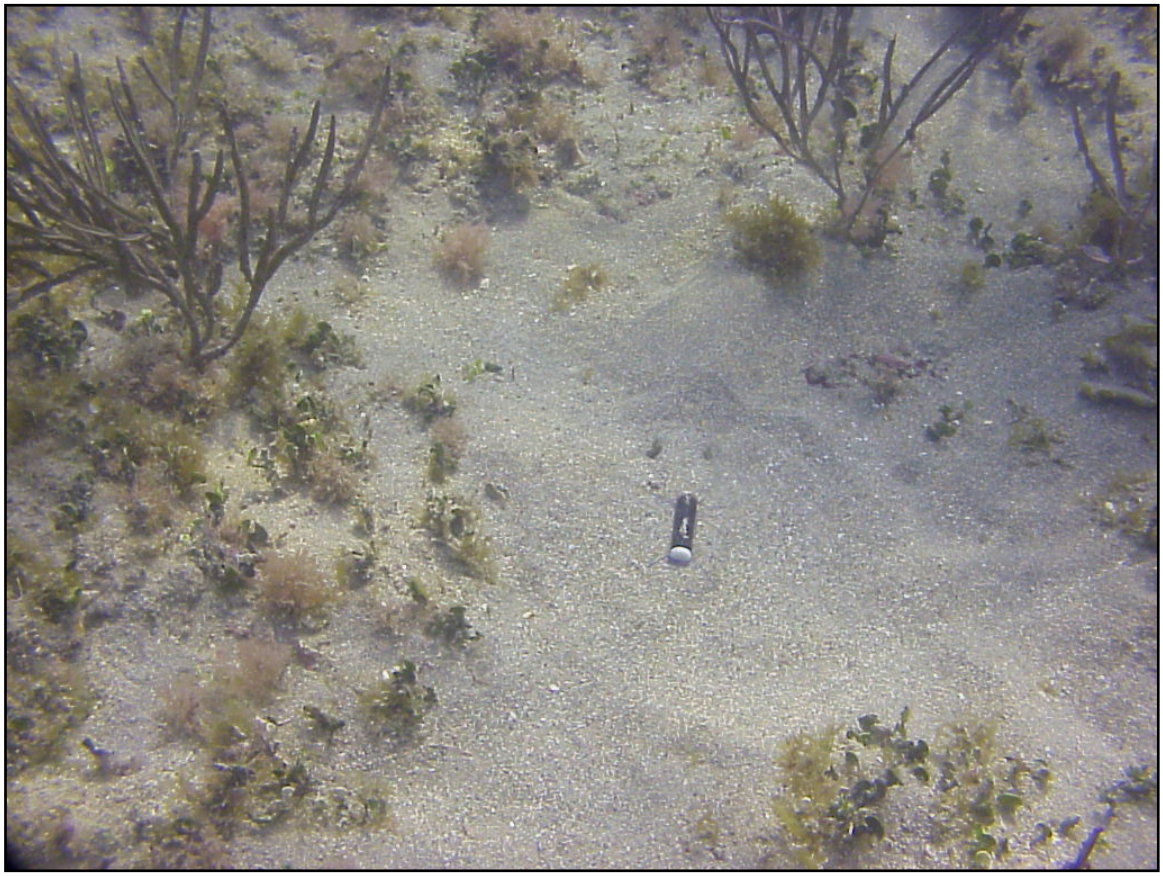


Figure 7. Stingray #11 (4-01-339) Just prior to recapture seen buried among a sand patch within the 1st reef with only the spiracles and telemetry tag visible.

All animals tracked were reproductively mature adults measuring 328 – 413 mm TL ($\overline{X}$ = 365 mm, ± 0.504 SEM) (Table 1). The onset of maturity for yellow stingrays is reported at a minimum size of 200 mm TL (Yañez-Arancibia & Amezcua-Linares, 1979 and Sulikowski, 1996). Stingray total body weight ranged between 300-500 g (estimated from length/weight data: Sulikowski, 1996 and the authors unpublished data), which establishes a tag to body weight ratio of 0.6-1% and meets the recommended 2% rule (Hawkins & Urquhart, 1983). Some authors have recently questioned the 2% rule and have suggested a revision to 8-12%, which would support a further reduction in the technical problems associated with weight constraints (Brown *et al*, 1999). Both laboratory observations and preliminary trackings of *U. jamaicensis* evidenced little to no effect on locomotion, feeding or burrowing capability of tagged stingrays.

Table 1. Stingray capture data: **(GES)** indicates a gestating female, **(TL)** total length, **(DL)** disc length, **(DW)** disc width – all size measurements are reported in mm and **(D)** depth in m. The Latitude and Longitude (WGS-84) indicate the initial capture sites for each animal. Duration is listed as maximum hours of continuous **(C)** and total days of intermittent contact **(I)** for each animal. Bold and highlighted print represents the **(8)** individuals tracked for a full diel cycle and used for statistical analyses. * Indicates tag was recovered, unattached to animal.

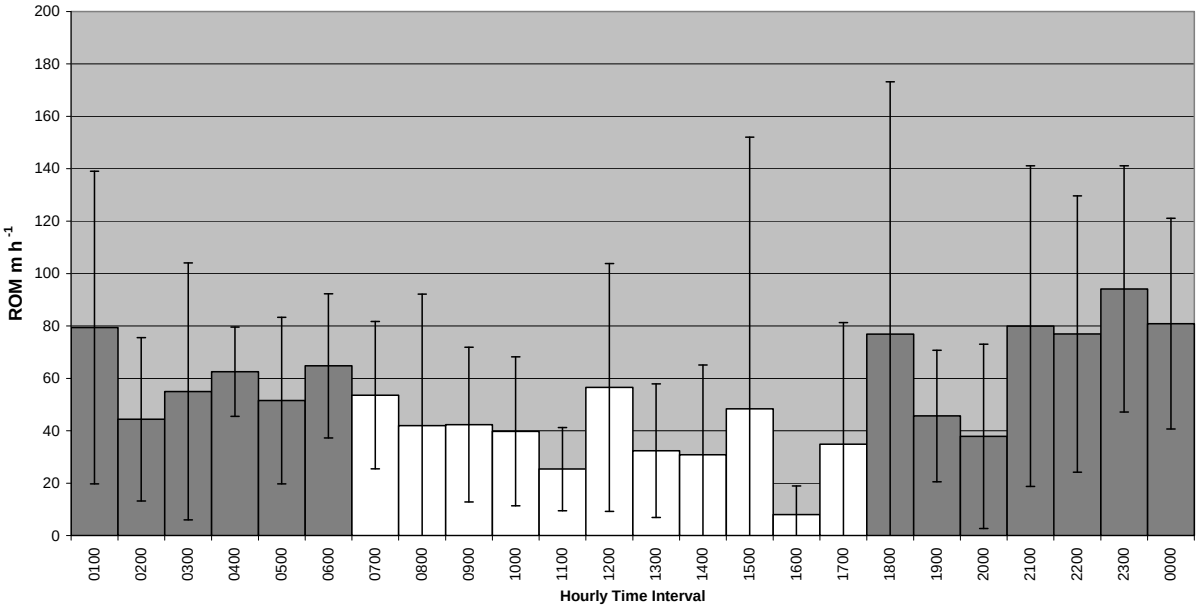
Date	Sex	Ray ID	TL	DL	DW	D	Latitude	Longitude	Duration
1/24/98	M	1/98-555	349	192	174	5.5	26 04.943 N	80 06.168 W	2h C/13d I
1/24/98	M	1-98-294	345	211	169	5.8	26 04.948 N	80 06.157 W	2h C/13d I
1/24/98	F (GES)	1-98-442	345	217	170	5.8	26 04.938 N	80 06.154 W	2h C/8d I
3/15/99	M	3-99-645	370	225	188	9.1	26 04.830 N	80 06.770 W	6h C/ 3d I
3/2/00	**F**	**3-00-357**	**350**	**220**	**180**	**8.5**	**26 04.696 N**	**80 06.784 W**	**26h C**
9/27/00	F (GES)	9-00-447	380	240	160	7.9	26 04.308 N	80 06.743 W	20h C/9d I
9/27/00	F	9-00-339	362	234	183	10.1	26 04.377 N	80 06.821 W	20h C/9d I*
12/12/00	M	12-00-456	372	220	191	10.7	26 04.268 N	80 06.733 W	14.5h C/6d I
1/16/01	**F**	**1-01-456**	**328**	**185**	**170**	**11.3**	**26 04.310 N**	**80 06.710 W**	**24h C/2d I**
1/16/01	**F (GES)**	**1-01-447**	**389**	**245**	**187**	**11.0**	**26 04.280 N**	**80 06.712 W**	**24h C/2d I**
4/16/01	**F (GES)**	**4-01-339**	**413**	**247**	**206**	**5.2**	**26 04.160 N**	**80 06.476 W**	**24h C**
4/16/01	**F**	**4-01-447**	**354**	**227**	**185**	**4.0**	**26 04.238 N**	**80 06.527 W**	**24h C**
5/22/01	**F (GES)**	**5-01-447**	**N/A**	**239**	**186**	**4.0**	**26 04.712 N**	**80 06.326 W**	**25.5h C**
5/22/01	**F (GES)**	**5-01-456**	**388**	**233**	**194**	**4.0**	**26 04.714 N**	**80 06.332 W**	**25.5h C**
8/23/01	M	8-01-339	345	214	183	4.9	26 04.357 N	80 06.392 W	4.25h C
8/23/01	F	8-01-456	366	224	196	4.9	26 04.420 N	80 06.392 W	4.25h C
9/25/01	**M**	**9-01-456**	**365**	**212**	**180**	**4.3**	**26 04.047 N**	**80 06.334 W**	**28h C**

Movelength distances (distance traveled per tracking interval) were non-normally distributed with unequal variances since the large proportion of zero distance movelengths skewed the data. A total of 494 distances were pooled across 8 individual stingrays. Nocturnal distances traveled ($\overline{X}$ = 25.91 m ± 1.61 SEM, n = 202) were significantly higher than the observed diurnal movements ($\overline{X}$ = 18.38 m ± 2.09 SEM, n = 195) (Mann-Whitney U-test [MW]: Z = -6.59, $p < 0.00001$). Crepuscular movements ($\overline{X}$ = 19.90 m ± 1.41 SEM, n = 97) were significantly different from both diurnal (MW: Z = -3.96, $p < 0.0001$) and nocturnal (MW: Z = -2.20, $p < 0.03$) movements. Results indicate there are progressively larger movements made from the diurnal (photophase) to the crepuscular phases with peak distances traveled occurring during the nocturnal phase (scotophase).

Likewise, the hourly rates of movement (ROM) for pooled individual stingrays were significantly much higher for nocturnal activities ($\overline{X}$ = 70.11 m h^{-1} ± 4.85 SEM, n = 97) than during the diurnal phase ($\overline{X}$ = 43.03 m h^{-1} ± 4.84 SEM, n = 77) (MW: Z = 4.82, $p < 0.00001$). Peak activity surrounded midnight, from 2100-0200 hours in most cases, (from pooled ROM) with a second trend of elevated activity during the midday or early afternoon **(**Figure 8). The maximum mean hourly rate of movement (ROM) recorded for all individuals pooled was 94.12 m h^{-1} (±16.61 SEM) during the 2300-2400 hour period, and an individual maximum ROM for stingray #13 (5-01-447) of 294.25 m h^{-1} during the 1800-1900 period. The greatest distance traveled in a single movelength was also by stingray #13 (5-01-447) for 246.65 m during the 1829-1850 tracking interval. The minimum mean rate of movement for pooled individuals was 16.02 m h^{-1} (±5.48 SEM)

during the 1600-1700 hour interval (for individual rates of movement charts, see Appendix F**)**.

Figure 8. Mean hourly rate of movement (ROM) for pooled (8) *U. jamaicensis* tracked for a full diel cycle. Light bars indicate diurnal activity, dark bars indicate nocturnal activity and error bars (+/-) SEM.



The Kernel Utilization Distributions (KUD) for eight individuals exhibited significant differences in the pooled 6h shift KUD (n = 32) with both the 95% KUD (MW: Z = -1.99, p = 0.046) and the 50% KUD (MW: Z = -2.07, p = 0.038) indicating larger total activity spaces and core areas during nocturnal periods. The total 24h KUD (n = 8) ranged considerably for both the 95% KUD ($\overline{x}$ = 21,402.5 m^2 ± 10,696.0 SEM) and 50% KUD ($\overline{x}$ = 5564.1 m^2 ± 2997.6 SEM). The diurnal mean for the 95% KUD (6-h pooled data) for 8 individuals (n = 32) was 4785.4 m^2 ± 1631.0 SEM with a (50%) KUD mean of 976.9 m^2 ± 430.8 SEM, whereas both the nocturnal (95%) KUD mean (9932.0 m^2 ± 3898.2 SEM) and (50%) KUD mean (1497.1 m^2 ± 486.0 SEM) were significantly larger (24-h KUD contours are provided in Appendix E**)**. No statistically significant difference was demonstrated for either the total 24h activity spaces or the core areas

between individuals (n = 8) in relation to season, from the Kruskal-Wallis test results (95% KUD) (H = 2.55, p = 0.2801) and (50%) (H = 1.60, p = 0.4501). However, sufficient tracking during the summer months was not achieved for the previous analysis to avoid a Type II statistical error and to determine the occurrence of a true difference.

Linearity indices (LI) provided variable results, but generally demonstrated confined movements for all animals tracked. Both the diel comparison (6-h data) and total linearity (24-h) achieved very low values, which are suggestive of strong site fixity and confined movements (Appendix G). The pooled 6h shift LI for eight individuals did not demonstrate any significant difference between day LI ($\overline{X}$ = 0.224 ± 0.056 SEM, n = 16) and night LI ($\overline{X}$ = 0.204 ± 0.037 SEM, n = 16) (MW: Z = -0.189, p = 0.851). The 24h LI demonstrated even smaller values for the total observed movements ($\overline{X}$ = 0.091 ± 0.030 SEM, n = 8) indicating overall confined movements. Even nocturnal movements, which were continuously monitored, demonstrated confined movements with only a general shift in location ($\overline{X}$ = 0.131 ± 0.047 SEM, n = 8).

Site fixity tests for total track movements demonstrated confined space utilization for all but two animals (Figure 9**)**. The simulated tracks (n = 1000), represented by blue lines, were compared with the observed track of each stingray. The stingrays #10 (4-01-447) (Figure 9a) and #17 (9-01-456) (Figure 9b) displayed random movements in relation to the low proportion of RW simulations with greater MSD and linearity values than observed tracks (p > 44.1% and p > 5.8%, respectively). All remaining stingrays had MSD simulation values that were significantly greater than observed values (p > 0.95 - 0.99). Therefore, 95% - 99% of the simulated RW tracks demonstrated significantly more random or dispersed movements than observed tracks, which indicates confined

movements for the remaining animals (Appendix H). Similar results were achieved for RW simulations, with the starting location originating at the COA in comparison to the initial location of the observed track.

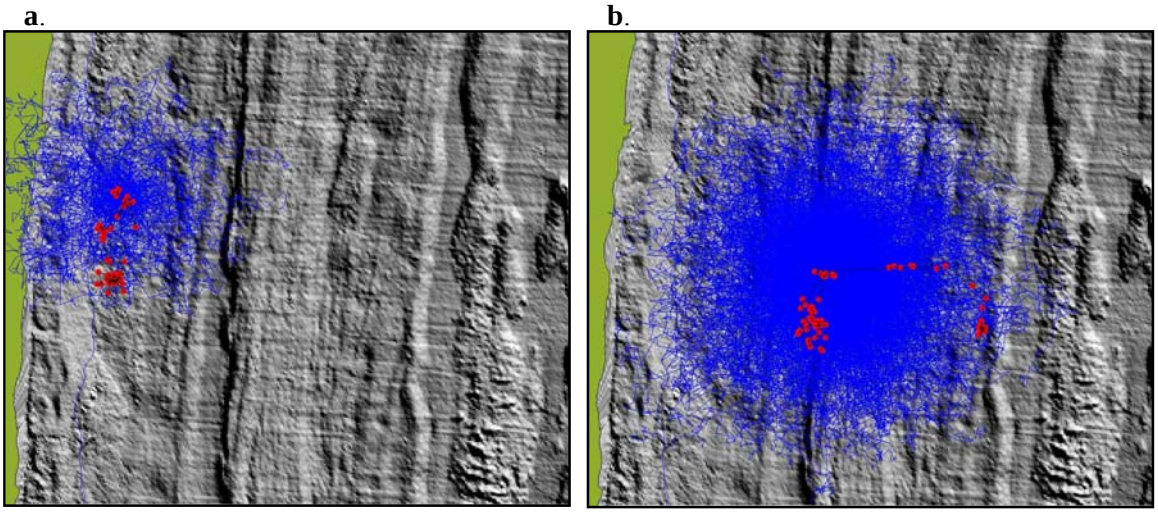


Figure 9. Site fixity tests for **a**. Stingray #10 (4-01-447) and **b**. Stingray #17 (9-01-456). Both stingrays demonstrated random movement patterns from comparison of the (1000) simulated tracks (blue lines) to the observed tracks (red locations).

4.2 Seasonal Distribution

Urobatis jamaicensis occurred in nearly13% of the 940 total individual point counts from the combined Broward County studies. Therefore, in coastal waters of Broward County, Florida, *U. jamaicensis* is considered common, especially among elasmobranch species (Total counts [n = 940, $\overline{x}$ = 0.128 ± 0.012 SEM], 1st reef [n = 370, $\overline{x}$ = 0.124 ± 0.019 SEM], 2nd reef [n = 292, $\overline{x}$ = 0.151 ± 0.024 SEM), and 3rd reef (n = 278, $\overline{x}$ = 0.108 ± 0.019 SEM], where the mean represents the frequency of observations from the number of counts conducted per reef). The maximum depth recorded was 33 m from the eastern edge of the 3rd reef, which extends the previously reported depth range of 25 m (Humann, 2002).

Seasonal comparisons indicated no significant difference for abundance between reefs (Appendix I, Table A). Likewise, the comparison of each reef between seasons did not demonstrate any statistically significant differences with a Kruskal-Wallis test (Appendix I, Table B). The comparison of each individual month demonstrated no significant difference between all three reefs with the exception of July (n = 52), which attained a marginal level of significance (KW: H = 5.87, p = 0.053). This resulted from no inshore observations of *U. jamaicensis* within the point count cylinder during the month of July (Appendix I, Table C). Comparisons for the 1st and 2nd reefs between months demonstrated no significant differences (n = 370, KW: H = 6.55, p = 0.834 and n = 292, KW: H = 12.59, p = 0.321, respectively); however, a marginally significant difference between months on the 3rd reef (n = 278) was observed (KW: H = 19.98, p = 0.046) (Appendix I, Table D). A series of MW tests were conducted on all possible combinations of months for *post-hoc* analyses to determine where the significant difference occurred within the 3rd reef data. The results revealed November differed significantly from most months and May was also significantly different from June (p < 0.004) and August (p < 0.03) (Appendix J). The marginal significance from the initial KW test was primarily a result of the relatively high number of observations in comparison to the low number of surveys conducted in November (3 rays/6 counts) on the 3rd reef.

4.3 Population Structure: Sex Ratio and Size Class

From the combined studies in Broward County and personal observations, total sex ratio was 276F:247M (Female:Male), which does not differ significantly from a 1:1 ratio (G = 1.61, p = 0.205). Throughout the year, there was no significant difference

between sex ratio for monthly observations across all three reefs (Appendix K-1). Females were observed more frequently on the 1st reef 127F:99M, but had ratios that were nearly identical to males on both the 2nd (116F:117M) and 3rd (33F:31M) reefs. The only example of possible seasonal gender segregation was during the spring inshore observations (March, April and May), where females outnumbered males, 20F:8M (G = 5.22, p = 0.022) (Appendix K-2). No other statistical analyses for the seasonal or monthly comparisons of the sex ratio on all three reef tracts evidenced a significant departure from a 1:1 ratio. Several categories also contained very small samples ($n < 6$) and were insufficient to detect a significant difference at the ($\alpha \leq 0.05$) level with a two-tailed binomial probability test (Zar, 1996).

Both genders peaked in frequency between 300-400 mm TL (classes 5 and 6) with the average size observed for the yellow stingray population in South Florida 300-349 mm (class 5) ($\overline{X}$ = 333 mm TL ± 0.248 SEM) (Figure 10). Females on average were slightly larger ($\overline{X}$ = 349 mm TL ± 0.347 SEM) than males ($\overline{X}$ = 326 mm TL ± 0.356 SEM). Sixty-seven adults ranged between 400-450 mm TL and there were 17 observations that exceeded 450 mm TL. The largest specimen recorded during all combined studies in Broward County was a female measuring 560 mm TL (observed in February 2003), which highlights the probable inaccuracy of the maximum reported size of *U. jamaicensis* (760 mm TL), mentioned earlier. Sex ratio among size classes demonstrated a significantly higher number of males in class 4 (250-299 mm, 17F:32M) (G = 4.62, p = 0.032) and class 5 (300-349 mm, 67F:107M) (G = 9.25, p = 0.002), whereas a highly significant number of females were observed in class 6 (350-399 mm, 129F:64M) (G = 22.27, p = 0.000002) and class 7 (400-449 mm, 44F:23M) (G = 6.65, p

= 0.01**)**. Numbers were similar in classes 2-3 with a slightly higher frequency of males in all categories. Both genders were of equal proportions in class 8 (450-499 mm) relatively speaking with only three females representing class 9 (500+ mm) (Table 2**)**.

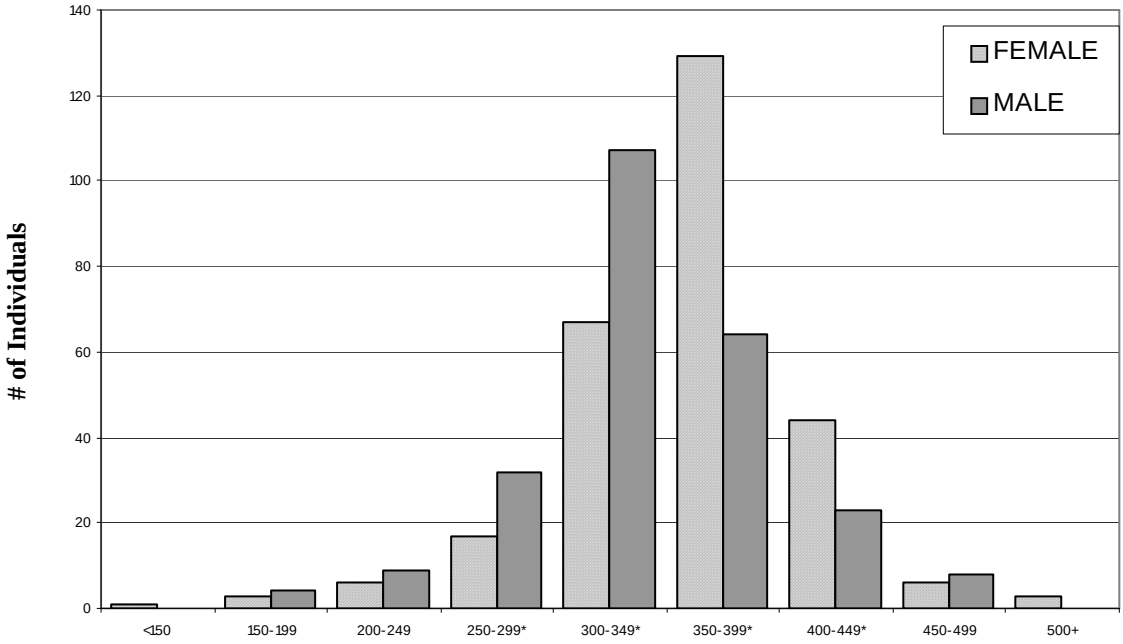


Figure 10. Size class (TL) frequency for female and male yellow stingrays in Broward County, FL (January 1998 – December 2003).

Table 2. Size class comparisons between genders, significant departures from a 1:1 ratio are highlighted in bold.

Size Class	Size	MALE	FEMALE	G (Williams)	*p*-value	Binomial *p*
1	<150mm	0	1	-	-	N/A
2	150-199mm	4	3	-	-	1.00
3	200-249mm	9	6	-	-	0.607
4	250-299mm	**32**	**17**	4.619	**0.032**	-
5	300-349mm	**107**	**67**	9.251	**0.002**	-
6	350-399mm	**64**	**129**	22.267	**0.000**	-
7	400-449mm	**23**	**44**	6.645	**0.010**	-
8	450-499mm	8	6	-	-	0.791
9	500+mm	0	3	-	-	N/A

From the combined Broward County studies and personal observations a total of 609 individual stingrays were observed (523 with gender identified) where size measurements, depth and reef location were recorded (Appendix L). Only three

individuals from size class 1 (<150 mm) were observed with one occurring on each reef (1st reef – June, 2nd reef – August, 3rd reef – April), however most neonates are 150mm TL or larger at time of birth (author, unpublished data). The majority of neonates (classes 1-2) were observed within the 1st and 2nd reefs (depth range 3-12 m), with smaller individuals generally observed in shallow water (<6 m deep) during June and August (Table 3). In addition, several neonates were born in captivity during the months of (January, August, October & November) but were not included in data analyses of field data. Slight size increases were associated with a marginal shift to deeper water, however, some smaller sized neonates were observed in deeper water with one particular female (129 mm TL) located 20 m west of the 3rd reef tract on a small hard bottom patch

Table 3. Monthly observations of *U. jamaicensis* neonates (*n* = 21).

Neonates	Month	Sex	Size (mm)	Location	Depth (m)
-	January*	0	N/A	N/A	N/A
1	February	M	152	INSHORE	6.1
-	March	0	N/A	N/A	N/A
2	April	F	129	OFFSHORE	22.0
-	May	0	N/A	N/A	N/A
3	June	M	160	INSHORE	4.0
4		UNK	130	INSHORE	3.1
5		UNK	170	INSHORE	4.0
6	July	UNK	150	MIDDLE	12.2
7		UNK	180	OFFSHORE	19.0
8	August*	F	150	INSHORE	4.6
9		UNK	150	INSHORE	4.6
10		UNK	150	INSHORE	4.6
11		UNK	150	INSHORE	6.4
12		UNK	140	MIDDLE	9.1
13		UNK	170	OFFSHORE	19.0
14		UNK	180	OFFSHORE	16.0
15	September	F	150	INSHORE	6.1
16		M	180	MIDDLE	6.1
17	October*	M	150	MIDDLE	12.2
18		M	180	MIDDLE	12.2
19		F	150	MIDDLE	12.2
20		UNK	150	OFFSHORE	16.5
-	November*	0	N/A	N/A	
21	December	F	170	INSHORE	15.0

in water 22 m deep. Animals from size class 2 (150-199 mm) were slightly more frequent, occurring on the 1st reef (n = 9) in (February, June, August, September and December) on the 2nd reef (n = 5) in (July, September and October) and on the 3rd reef (n = 4) in (July, August and October). Overall size classes (1-3) were represented by lower combined numbers of individuals (n = 48), whereas an initial increase was observed inshore for size class 4 (250-299 mm) (25 total - 1st reef, 36 total - 2nd reef and 8 total - 3rd reef). The sudden increase in numbers for size class 5 (300-349 mm) in particular along the 3rd reef (n = 29) may include the possible onset of an ontogenetic shift in habitat or an expansion of area utilized. The total number of observations provides data for further comments to seasonal distribution (see discussion), but due to uneven sampling the results were biased and not used for any additional statistical analyses.

4.4 Comments on Reproduction

Field observations identified females actively gestating during all months of the year (Figure 11). Mid to near-term gestating females are easily recognized from obvious enlargements of the posterior dorsal region, where near-term young can often be seen actively moving (Figure 12). Although near term females were observed on numerous occasions, parturition was never witnessed during any field observations from the combined studies. February (19N:3G, Binomial p = 0.0009) and October (32N:11G, G = 10.59, p = 0.001) were identified as periods when non-gestating females (N) were significantly more abundant than gestating females (G). Both February and October are likely associated with separate peaks in the annual ovulatory cycle. May (3N:15G, Binomial p = 0.008) had a significantly higher number of gestating females (most in advanced stages) followed by the dramatic increase in non-gestating females in June,

suggesting the onset of a parturition period during these months. All other months did not deviate significantly from a 1:1 ratio (Table 4).

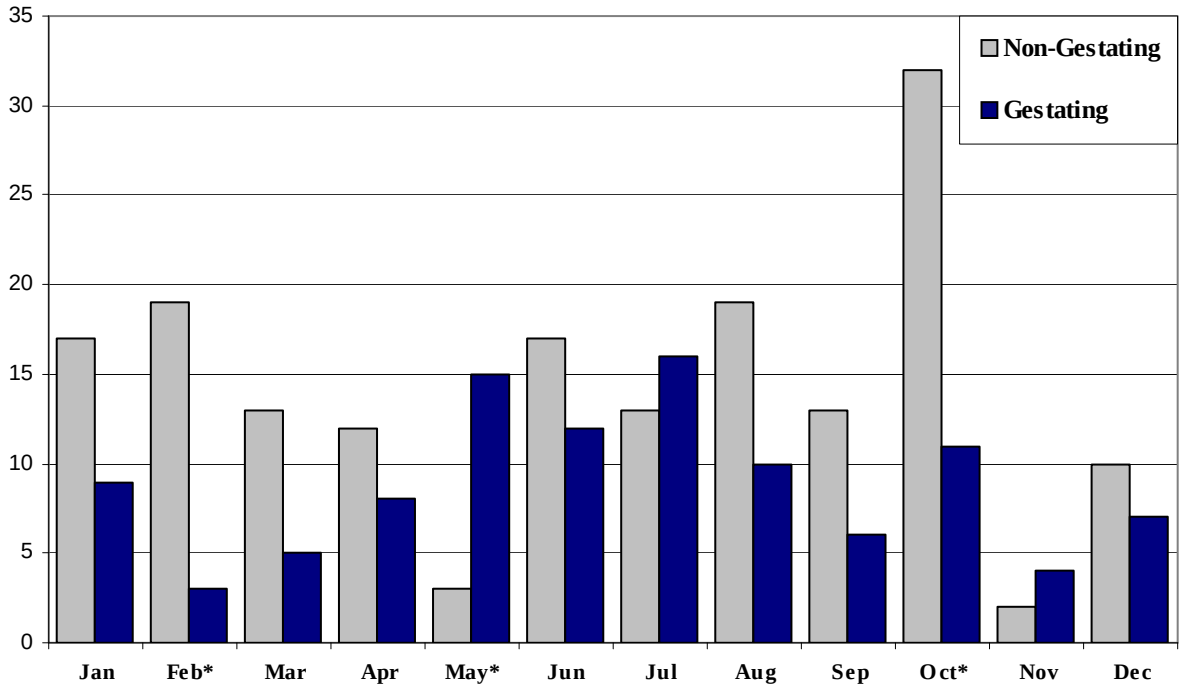


Figure 11. Monthly field observations of gestating and non-gestating female *U. jamaicensis*.

Figure 12: Near-term gestating female on the inshore reef (December 16, 2000).

Table 4. Monthly results of expected vs. observed frequencies for the ratio of Non-gestating (**N**) to Gestating (**G**) female *U. jamaicensis*. *G*-test performed for all months with sample size $n > 25$ and binomial probability test for all sample sizes $n < 25$. Significant deviations from a 1:1 ratio are highlighted in bold.

	N:G	**G (Williams)**	***p*-value**	**Binomial *p***
January	17:9	2.46	0.117	-
February*	**19:3**	-	-	**0.001**
March	13:5	-	-	0.096
April	12:8	-	-	0.503
May*	**3:15**	-	-	**0.008**
June	17:12	0.852	0.356	-
July	13:16	0.306	0.580	-
August	19:10	2.791	0.095	-
September	13:6	-	-	0.167
October*	**32:11**	10.585	**0.001**	-
November	2:4	-	-	1.00
December	10:7	-	-	0.629

Seasonal comparison among individual reefs also exhibited a non-gestating to gestating ratio significantly different from 1:1 on several occasions (Table 5). All three reefs and all four seasons were subject to fluctuations in the reproductive condition of observed females. During the spring on the 1st reef there was a significantly higher number of gestating females observed (5N:15G, Binomial $p = 0.041$) with all other deviations from a 1:1 ratio associated with a higher number of non-gestating females (6N:0G, Binomial $p = 0.031$, 3rd reef in summer), (27N:6G, $G = 14.24$, $p = 0.0002$**,** 1st reef in autumn) and (33N:14G, $G = 7.82$, $p = 0.005$, 2nd reef in winter) (Appendix M).

The apparent size at birth ranges between 129-175 mm TL. This variation is likely due to the size and age of the mother (uterine accommodation and ova production) and the current litter size (which influence the amount of maternally derived nutritional input received by each offspring) (author, unpublished data). As stated earlier, most neonates in particular smaller-sized individuals were observed in shallow water (< 6 m) with many counted during the summer months of June and August. Although a general trend of inshore parturition is recognized, the occurrence of neonates and small young-of-

year (YOY) across the entire study region indicates locally either the short-term use of an inshore nursery or parturition is unrestricted throughout various habitats. Adult females, particularly from class 6 (350-399 mm TL) predominated the inshore region throughout the year ($n = 63$), which further suggests the existence of a breeding and nursery region.

Table 5. Seasonal results of expected vs. observed frequencies for the ratio of Non-gestating **(N)** to Gestating **(G)** female *U. jamaicensis* for three reef tracts. *G*-test conducted for all months with sample sizes $n > 25$ and binomial probability test for all samples sizes $n < 25$. Significant deviations from a 1:1 ratio are highlighted in bold. Winter observations on the 3rd Reef ($n < 6$) were insufficient for data analysis.

1st Reef

	N:G	G (Williams)	*p*-value	Binomial *p*
SPRING	**5:15**	-	-	**0.041**
SUMMER	33:27	0.596	0.440	-
AUTUMN	**27:6**	14.239	**0.0001**	-
WINTER	10:4	-	-	0.180

2nd Reef

	N:G	G (Williams)	*p*-value	Binomial *p*
SPRING	12:9	-	-	0.668
SUMMER	10:11	-	-	1.00
AUTUMN	15:13	0.140	0.708	-
WINTER	**32:14**	7.822	**0.005**	-

3rd Reef

	N:G	G (Williams)	*p*-value	Binomial *p*
SPRING	11:4	-	-	0.118
SUMMER	**6:0**	-	-	**0.031**
AUTUMN	5:2	-	-	0.453
WINTER	4:1	-	-	N/A

5.0 Discussion

5.1 Telemetry

Detrimental effects from external tagging were not observed during this short-term tracking study. Weight ratios between study animals and telemetry tags were kept below the 2% maximum as recommended (Hawkins & Urquhart, 1983). In addition the demersal lifestyle of yellow stingrays would not be affected by tag weight in the manner a continuously swimming animal would experience (Stasko & Pincock, 1977).

Diurnal activity was intermittent with various periods of little to no movement, whereas the nocturnal phase exhibited increased rates of movement and larger distances traveled. The increased nocturnal activity patterns may suggest a peak in foraging behavior in correlation to the timing of prey species activity. The main food items for the local population are primarily polychaetes and small crustaceans (Quinn, 1996), which burrow among the sediment and hardbottom and generally exhibit nocturnal activities (Brown, 1961, Palmer, 1974 & Cutler, 1994). However, in Quinn's (1996) study *U. jamaicensis* was determined to be an opportunistic generalist where all but one of the 31 total rays collected at various times of day contained stomach contents. Diurnal observations have noted active individuals, however in most cases, and during all direct observations of tracked stingrays, diurnal observations have been of inactive animals either buried in the sediment or resting uncovered on the substrate (author, personal observation).

Crepuscular movements were statistically greater than diurnal observations but less than the distances traveled during the nocturnal phase. Although there was a slight degree of overlap between the standard errors of crepuscular and diurnal observations, a significant difference was determined with a Mann-Whitney *U*-test. During the evening twilight, both prior to low light levels and immediately following dusk most animals moved outside of their 50% UD core areas, which further suggests the possible initiation of foraging activities. Oftentimes a second late increase in nocturnal activity was evidenced prior to the dawn twilight, followed by reduced movements after sunrise. Movements generally consisted of a meandering pattern within a concentrated area but occasionally involved a more linear path of travel.

The longest individual movelength observed of 246 m/15 min demonstrated the ability of *U. jamaicensis* to cover considerable distances in a relatively short period of time. Therefore, telemetry study results (maximum mean ROM for pooled individuals was 94.12 m h^{-1}) suggest a gross underestimation of movement capability when swimming is sustained in a single direction. Point to point distance calculations characteristically underestimate the actual movement rates of free-swimming animals (Morrissey & Gruber, 1993a and Cartamil *et al*, 2003). On-going research with the congener *U. halleri* in Californian waters has evidenced similar trends of confined movements coupled with an occasional dispersal of over 1 mile (1.61 km) within several hours (C. Lowe, personal communication). Thus, short-term movement observations for both species appear to consist primarily of meandering movements within a semi-confined area, alternating with frequent periods of inactivity.

Although many consecutive positions were recorded in close proximity to one another, the existence of small-scale movements within the range of error cannot be discounted. The benthic lifestyle of batoids in general can make identifying sites of concentrated foraging versus those of refuge difficult with telemetry. Current behavior exhibited by an individual can be misleading in categorizing activity type due to the availability of resources or suitable stimuli. Thus, forage sites with high prey densities may involve increased activity but not be associated with large travel distances and mistakenly be considered a refuge site with little or no activity. Or, the movement of an animal in a refuge site with adequate food resources may not demonstrate a clear relationship to the diel cycle if foraging behavior is not elicited until feeding becomes necessary. Studies encompassing metabolic rates, bioenergetics and daily food intake are

required to better understand the relationship between foraging behavior and diel movements. A number of animals were observed actively foraging and exhibiting small-scale movements during the daytime, whether these activities were in response to some behavioral stimuli or were simply due to a generalist/opportunistic behavior is unknown.

During a reproductive study on the congener *U. halleri*, morning aggregations of females were observed buried in the sediment, while males continually swam throughout the area (Nordell, 1994). The researcher suggested the males were likely searching for receptive females, since no males were observed foraging in the morning hours during the mating period of the study. Since the majority of animals tracked in the current study were female it was not possible to determine any variation in activity patterns based upon gender, particularly in response to mating behavior. However, it is noteworthy that the individual displaying the largest extent of diel movements was the single male (9-01-456) tracked continuously for 24 hours.

Space utilization of *U. jamaicensis* paralleled the results achieved from diel activity patterns. Although utilization distributions for most tracked stingrays exhibited confined spatial patterns with evidence of multimodality (repetitive use of a specific area), larger nocturnal space utilization was determined to be statistically significant from the 6-h divided KUD data. Many animals appeared to meander in a circular fashion within a concentrated area, which may have reduced the overall size of the area utilized. In addition, small-scale activities may take place within a very confined radius and may go unnoticed until larger moves are performed. Likewise, GPS limitations and tracker-induced errors may have indicated small movements when none actually occurred. The tracking schedule also may have affected the observed results since daytime data were

non-continuous and divided between the nighttime tracks (often spatially partitioned). This made combining separate daytime locations for the construction of KUD invalid as it would inflate the KUD areas. Thus, the data were analyzed as individual 6-h intervals for KUD determination.

The division of the total track into four periods (6-h shifts) to deal with the partitioning of diurnal data may not accurately demonstrate the true nature of the diel KUD and likely resulted in the underestimation of KUD size for nocturnal observations, since the characteristic modal distributions would generate multiple smaller areas due to the high density of successive locations. Future research conducting short-term tracking should eliminate this situation by initiating all diel tracks during the onset of twilight periods to ensure the collection of continuous diurnal and nocturnal data. The current study was unable to avoid splitting the diurnal tracking period due to conflicting times of both personnel and boat availability, combined with fluctuating weather conditions. Despite these minor drawbacks, the data achieved was still sufficient to establish a significant difference between diel phases.

Stingrays repeatedly returned to specific areas (multimodality), often exploring adjacent locales before performing a circular pattern or directed moves back to a region of previous use. This pattern of movement was generally non-random with numerous instances of an outward radiating pattern with a return to the centrally positioned core site. Occasionally stingrays returned to an area previously occupied on a separate day, some animals in particular would return to the capture site midway through the ongoing track. Several animals were monitored across multiple days (due to weather delays or intermittent preliminary tracks) and also were consistently located in the general area of

previous positions. Stingrays #1 and #2 (1-98-294 & 1-98-255) were both relocated in close proximity to their initial site of capture for nearly two weeks, displaying very little displacement. Poor weather that persisted for nine days would have allowed sufficient time for extensive moves away from and back to the region, however, the lack of data can not confirm or deny behavior while tracking was suspended. Stingray #7 (9-00-447) initially displayed movements around a centrally located position, yet also traveled greater distances along a prominent edge within the 2nd reef during the latter half of the track. After an extensive move south the animal was eventually recaptured a week later slightly north of the original capture site (Appendix E, Figure E). This behavior indicates that the observed diel activity patterns may represent only a portion of the overall range yellow stingrays utilize on a normal basis.

Home range analyses were not performed since the short-term data was insufficient to achieve an asymptotic relationship between the number of locations and the area utilized (Harris *et al*, 1990 and Bolden, 2001). However, several animals tracked intermittently, exhibited temporary periods of site fidelity for as long as 13 days. Therefore, yellow stingrays likely possess home ranging behaviors, but this behavior may only occur seasonally or temporarily with a periodic shift in habitat or region. *U. halleri* has been noted to display restricted movements with a return to specific regions year after year (Campbell, 1951 and Babel, 1967).

Short-term movements of Pacific angel sharks (*Squatina californica*) were observed to be very confined with researchers initially determining the existence of a small home range (Standora & Nelson, 1977). A follow up study with longer-term intermittent tracking exhibited small temporary areas utilized with periodic range shifts

resulting in dispersed movements around the Santa Catalina Island (Pittenger, 1984). Studies on jaguars (*Panthera onca*) and leopard cats (*Felis bengalensis*) have also indicated the use of small areas, followed by periodic shifts to other portions of the full range (Rabinowitz & Nottingham, 1986 and Rabinowitz, 1990). Feral cats (*Felis catus*) in central Australia possessed long-term home ranges that were significantly larger than 24-h home ranges, making small shifts within the boundary of the total HR after occupying the smaller ranges for periods of 1-2 days (Edwards *et al*, 2001). Range use by *U. jamaicensis* may be similar where a temporary home range is maintained with a periodic shift to a separate region or multiple smaller daily ranges are utilized sequentially within the confines of a larger and more consistent home range.

Using data from several days of contact with stingray #8 (12-00-447) provides a recognizable example of a larger overall range with multiple smaller daily KUD. Total 95% KUD calculations for all locations demonstrated a larger area of 23,072.4 m^2 in comparison to 4580.8 m^2 and 1664.1 m^2 on the separate days of continuous tracking (12/12-12/13/00) and (12/14/00), respectively. A total area of 18,621 m^2 was established from the minimum convex polygon (MCP) generated in AMAE to measure the entire area located within the point distribution of all stingray #8 locations. Thus in this animal, a much larger range is noted across several days in comparison to the tracks conducted for only a portion of the diel cycle.

The marginal significance levels for kernel distributions, in particular between core areas of activity, are not representative of the decreased activity noted during diurnal periods. Rather, the coupled effects of intermittent diurnal activity and repeated returns to specific locations at night may have created more evenly distributed probability

densities between both sets of data. It also may be difficult to see a difference in core area use when the lifestyle of stingrays often shows a continuous occupancy of small patches for resting over periods of time and foraging behaviors within a limited area. This type of behavior is exemplary of the optimal foraging theory where a patch with greater resources (e.g. high prey density) is selected over an area with less nutritional value (Pyke *et al*, 1977, Iwasa *et al*, 1981, Ford, 1983). However, recent findings by Heupel and Hueter (2002) suggest predator avoidance among juvenile blacktip sharks, *Carcharhinus limbatus* in Terra Ceia Bay, Florida may be a more important factor in determining regional habitat use opposed to the use of areas with higher prey abundance. Thus, the restricted movements and high levels of site fixity of the study rays might support predator avoidance through cryptic behavior within the more complex hardbottom reef communities. The difficulty locating most animals during a portion of their track was contributed to refuge at or near areas of high complexity, causing transmitter signal interference.

The sedentary and cryptic behavior of the study rays frequently caused problems in determining accurate locations while tracking. Stationary behavior can often coincide with tracking interference from the surrounding habitat (i.e. animals generally seek refuge along some form of complexity), which often blocks the acoustic signal. On numerous occasions during this study, animals were tracked to within several meters of the boat (determined by signal intensity) only to lose the signal within a closer range. On these occasions, it was generally necessary to alter the direction of approach to avoid the bottom topography or biota interfering with line of site detection of telemetry tags. Stingray #7 (9-00-447) was recaptured partially hidden under a small rocky outcropping

after experiencing difficulty in achieving a ground zero position. The transmitter signal was only detected from the direction facing the opening of the cave-like rock from a distance greater than 3 – 4 m.

Animals that were originally captured within the interior of the 1st or 2nd reef structure generally displayed more confined activities with a distinctive circular distribution of movement locations. Both of the regions are relatively consistent in structure, being moderately flat hardbottom with numerous areas of patchy sand. Stingrays that were captured closer to the edge of a reef tract often displayed more elongated movements and traveled along the hardbottom edge contours. Linear movements were often associated with the eastern portion of the second reef, which has a gradually sloping characteristic from a shallow crest (5 m) down to the reef edge (15 m) where there is a large sand flat. Stingrays adjacent to prominent ledges (high relief structures within the interior of the 1st and 2nd reefs) also demonstrated a tendency to make linear moves, following the profile of the landscape. Therefore, benthic habitat composition appears to influence the direction of movements (linear moves along ledges and boundaries) and space utilization (preference of hardbottom with patchy sand for refuge sites). Juvenile lemon sharks (*Negaprion brevirostris*) used depth contours, preferring shallow waters with rocky or sandy substrates as a possible means of predator avoidance (Morrissey & Gruber, 1993b.). Only two stingrays ventured off the reef area during telemetry tracking, each represented by a single location among the adjacent rubble zone (#9. 1-01-447), followed by an immediate return onto the hardbottom community or a quick directed move between reefs (#17. 9-01-456). In addition, nearly all of the direct observations made during this study were located within the reef structure

with few instances of yellow stingray occurrence between reefs (presumably habitat edge foraging or between reef dispersal).

Although detailed analysis of habitat selection was not conducted, an obvious preference for hardbottom substrate over the intermediate sand flat regions was readily noticeable during this study. Further research with long-term tracking, using a bottom-mounted array in combination with direct observations is necessary to establish a more detailed description of the relationship between the benthic landscape and habitat selection. However, the use of small to moderate sized sand patches within the reef community appears to be the preferred habitat type when seeking refuge for periods of longer duration. In addition, the use of sand channels as a corridor for directed movements is possibly a source for future investigation; however, detailed habitat mapping is required to realize this to the fullest potential. The influence of heterogeneous landscapes on animal movement patterns has been implicated in various ecological processes including predator avoidance, foraging behavior and rates of dispersal (Johnson *et al*, 1992).

Linearity results for both 24-h tracks and individual 6-h divided tracks also indicate a meandering re-use of a confined area since most values were close to zero. Even individuals that demonstrated some dispersal from the capture site initially displayed confined movements or consistently returned to a core site before making a more directed move away. Preliminary tracks observed two out of three animals remaining within 100 m of the original capture site for at least 13 days. Stingray #8 (12-00-447) utilized a large area across 6 days of contact, moving first north and then south of the original capture site. The site fixity tests also implied that 24-h diel movements are

typically restricted in patterns of space utilization. However, stingray #7 (9-00-447), which was not included in the statistical analyses because it was not tracked for a full diel cycle, did demonstrate a random movement pattern with an extensive and directed move south during the 20-h track (Appendix E, Figure E). Future diel tracks of the same individual across multiple days could establish day-to-day overlap of use and potentially verify site fidelity and areas of concentrated use for foraging and refuge. Additional long-term tracking is also necessary to determine site fidelity, which is a necessary criterion for establishing home ranging behavior (Cooper, 1978, Spencer *et al*, 1990, White & Garrott, 1990, Hooge *et al*, 2000).

Although habitat structure was demonstrated to be an important factor in movement patterns, additional environmental influences remain largely unknown. Unlike other studies (Teaf, 1980, Blaylock, 1988, Silliman & Gruber, 1999), non-structural physical parameters (e.g. tidal flow) did not appear to play a major role in influencing either the distribution or directionality of movements. The majority of studies experiencing tidally induced movements have been conducted in bays and estuaries, where tidal currents are more pronounced and high tides expand the foraging area available. Although this is not the situation in Broward County there is a complex current regime within the study area, due to periodic eddies generated by a close proximity to the Florida Current and tidal discharge from Port Everglades Inlet. Rapid shifts in the direction of current flow have been evidenced and warrant further investigation in combination with tracking studies (author, personal observation).

5.2 Seasonal Distribution

The point count data from the combined Broward County studies suggests that the population of yellow stingrays off Broward County is widespread throughout the region and occur year round. From the 940 total counts examined, *U. jamaicensis* was common and occurred in nearly 13% of all point counts. The point count data indicated only a marginal difference between *U. jamaicensis* population distributions across all reefs throughout the entire year. Seasonal comparison of all three reefs resulted in no significant differences in stingray distributions with only July having a marginally significant difference. However, the minimal number of point counts conducted inshore during July (n = 7), resulting in no observations of *U. jamaicensis*, suggests this difference be regarded with caution. However, supplemental data from personal observations indicated frequent observations of *U. jamaicensis* inshore during July. Likewise, the comparison of individual reefs on a seasonal basis showed no significant difference, but during monthly analyses the 3rd reef was marginally significant, as November differed significantly from nearly all other months. This difference is also suspect as it was due to the relatively high number of yellow stingray observations in comparison to the low number of surveys conducted in November (3 rays/6 counts).

Data from the combined Broward County Studies and personal observations lead to the conclusion that the local population exhibited permanent residency and did not demonstrate any clear seasonal patterns of distribution related to annual temperature variation. Bottom temperatures in the region generally experience a minimum of 18ºC (personal observation), which apparently does not produce a limiting factor on

distribution. There is currently insufficient evidence to support any seasonal variation in distribution of the coastal Atlantic population of yellow stingrays in South Florida.

The point count method has drawbacks in regard to the detection of yellow stingrays. The technique is somewhat limited in its ability to detect cryptic species, particularly small animals situated along the margins of the count or hidden within areas of increased complexity. In addition, yellow stingrays are frequently buried in the sediment and thus easily overlooked in a visual census. In future studies a different census technique (i.e. belt-transect) is recommended to cover a larger area and improve the methodology for studying yellow stingray distribution.

5.3 Population Structure

Gender segregation has been observed among numerous elasmobranchs and is often attributed to a function of the reproductive cycle, which may reduce competition for resources while females are gestating (Babel, 1967, Klimley, 1987, Smith & Merriner, 1987 and Nordell, 1990). Ontogenetic partitioning has been attributed to swimming ability and/or dietary shifts related to prey consumption capabilities (Smith & Merriner, 1987), or nearshore regions and estuaries may serve as a nursery for young following parturition (Babel, 1967, Sage *et al*, 1972, Thorson, 1983 and Smith & Merriner, 1986). Large numbers of gravid females are often observed inshore particularly during summer months, suggesting the possible existence of gender segregation and the establishment of a nearshore nursery for *U. jamaicensis* in South Florida (author, unpublished data).

There was little evidence for gender segregation observed during the course of this study. However based upon total observations, females were observed more frequently on the 1st reef than males. The only instance when gender segregation was

identified was during the spring (March, April, May) inshore observations. These observations were predominantly associated with a higher number of females (mostly pregnant) during the latter months and occurred just prior to an increase in neonate presence (onset of parturition). Near-term females have also been observed inshore in very shallow water during the summer months in larger numbers; however, males are still present and may be attracted to either recent post-partum females or pre-ovulatory females that are present in the same area. Babel (1967) determined mature female *U. halleri* were segregated further offshore in California, moving shoreward in June for mating and again in September to bear young. The local yellow stingray population may segregate during certain portions of the reproductive cycle, however, reproductive activity appears to occur year-round with an undetermined number of matings and litters annually (author, unpublished) (see discussion on reproduction below).

Even when gender segregation does occur, it may be difficult to distinguish if only partial segregation exists, due to a range in the timing of ovulation and length of gestation. Researchers have noted that only the portion of the female population of blackchin guitarfish (*Rhinobatos cemiculus*) that is actively in breeding condition will emigrate inshore (Capapé & Zaouali, 1994). The occurrence of actively gestating *U. jamaicensis* females in all months of the year and a short gestation period would seem to indicate yearlong mating or multiple matings, in contrast to a scenario of complete segregation of genders with a defined mating period.

Another alternative when gender segregation is not evident is "social segregation" where males and females form separate groups in respect to habitat or spatial use even though the ranges of each gender overlap (Conradt, 1998). Although most observations

were of single individuals, periodic observations of multiple individuals have noted a tendency for consexuals (mostly gestating females) to occur together or in close proximity. However, since most observations have only consisted of an individual yellow stingray the social aggregation of consexuals for a majority of the year has not been indicated. Thus, the case for potential gender segregation appears much more complex than simple spatial partitioning by depth and requires further investigation to fully elucidate the population structure of *U. jamaicensis*. More extensive sampling to conduct nearest-neighbor contingency tables from precise locations (i.e. GPS stamped video) would be required to determine if a non-random congregation or distribution of genders exists.

A rapid growth during the first year of life has been documented for yellow stingrays in previous studies (Yañez-Arancibia & Amezcua-Linares, 1979 and Sulikowski, 1996). A high rate of mortality may also exist, but the abundance of mature stingrays (300-450 mm) in this study would likely support a conclusion of high growth rates to maturity. The possibility does exist for ontogenetic partitioning of habitats or the small size of neonates (~150 mm TL) could make it more difficult to locate younger individuals during field observations. In captivity, neonates have proven to be very difficult to locate without disturbing the sediment and were often found within rock crevices and areas of increased complexity (author, personal observation). Whereas, the few neonates that were observed or collected in the field were located in areas of low complexity and primarily in shallow waters of the inshore hardbottom.

Although neonates were present on all three reefs, the majority of all observations was made on the 1st reef and indicated a possible nearshore nursery. Additionally, most

cases where loose aggregations of yellow stingrays occurred have consisted of near-term pregnant females in shallow nearshore water, which further corroborates the existence of an inshore nursery. The presence of adult *U. jamaicensis* on the inshore reef throughout the year may or may not complicate the status of a nursery, since resource partitioning of prey items has been demonstrated among other urolophids between age classes (Babel, 1967, Edwards, 1980, Platell *et al*, 1998). However, due to the lack of substantial neonate observations during this study, no conclusions could be drawn on the specifics of nursery location or length of neonate residency inshore.

The shift from size class 4 (200-249 mm) to 5 (250-299 mm) not only involved a dramatic increase in numbers but also demonstrated a clearer presence of mature stingrays along the 3rd reef (particularly in males when sex was identified). Most if not all individuals from size class 5 should be sexually mature adults, which lends support to an ontogenetic shift in habitat or an expansion of range use. The size difference between genders (size classes 4-7) is likely due to a larger size achieved by females, presumably to accommodate larger litters (up to six young) during gestation. However, Babel (1967) reported similar size at sexual reproduction for both male and female *U. halleri* (145 mm DW and 146 mm DW, respectively). Nonetheless, if males matured at an earlier age or size, the reduction in energy for somatic growth could be reallocated to reproductive effort. Likewise, assuming that female fecundity is correlated with size, it would be non-advantageous for early sexual maturation due to a reduction in ova production and litter accommodation. These reasons could explain the gender variation in size for the larger size classes and reproductively mature population of *U. jamaicensis* in South Florida. The only other alternative is an inherent sexual dimorphism that leads to either faster

growth rates or a larger maximum size of female stingrays to accommodate embryonic development. This situation requires further research to determine if size at parturition differs between genders, as well as, additional age validation studies to verify if size varies between genders within age groups.

5.4 Reproduction

Although pregnant females were observed during all months of the year, two noticeable peaks in near-term individuals were observed during this study. Spring entailed the onset of the first reproductive cycle and is noticed from the lack of observed females gestating during February, steadily increasing through the following months with numerous pregnant animals inshore particularly during May (5N:15G). Young's (1993) suggestion of peak copulation in February and March would correlate well with the observed gravid females in June and a reported three-month gestation period (Jezior & Hamlett, 1994). Equivalent ratios of gestating and non-gestating females are noticed during the summer months with elevated numbers of gestating females on both the 1st (33N:27G) and 2nd (10N:11G) reefs, which demonstrates a likely overlap in the two peak breeding periods. Interestingly, there were no gestating females observed at any time on the 3rd reef during the summer months (6N:0G), which further suggests females may give birth inshore and establish a nursery for their young. The autumn months are associated with a significant drop in gestating females inshore (27N:6G), however, pregnant animals are still noted on the 2nd reef in sufficient numbers (15N:13G). A similar trend is noticed during the winter months with additional animals located along the 2nd reef, regardless of reproductive status.

There are three possible scenarios to describe the female reproductive cycle for *U. jamaicensis*. 1.) Biannual/semi-annual cycle with all females capable of producing two or three litters each year; this has also been suggested for *Urolophus paucimaculatus* (Edwards, 1980), as well as, *Potamotrygon circularis* and *P. motoro* (also small tropical batoids) (Thorson, 1983 and Thorson *et al*, 1983), 2.) Asynchronous timing of ovulation with two distinct reproductively active populations of females; as described for *U. halleri* (Babel, 1967) or 3.) Yearlong reproduction with no distinct breeding period, which can involve single or multiple litters annually. Males are likely sexually active for the majority of the year and/or are capable of storing sperm for periods after spermatogenesis has terminated, allowing them to persist in sexual activities (Spieler & Hamlett, unpublished data). Multiple mating events would appear likely; sperm storage by females during gestation resulting in a second litter cannot be ruled out at this time but appears unlikely (W.C. Hamlett, personal communication).

Carrier *et al* (1994) suggested that parturition and copulation might be synchronized to provide an olfactory cue for mating receptiveness. This behavior has also been suggested for mating pair formation among other elasmobranchs (Johnson & Nelson, 1978). Tricas *et al* (1995) reported the use of electroreception by male *U. halleri* in localization of females from distances of less than 1m with no evidence for olfactory cues. However, personal observations during the current study have witnessed a likely use of olfaction for locating potential mates, with males initiating search and following behavior of females from substantial distances. Whether electroreception or olfaction is the final sensory cue that determines female receptiveness or male copulatory orientation

is undecided; no observations of mating or successful pre-copulatory behaviors were witnessed during this study.

Presently, the annual fecundity, number of mating events and female readiness for copulation following parturition is unknown. Many articles on batoids have stated remaining ovarian eggs during gestation are atretic; however, more research is necessary to determine if vitellogenesis actually occurs in parallel with gestation and if females are again ready to ovulate upon parturition (Thorson, 1983, Capapé & Zaouali, 1994 and Henningsen, 2000). A study encompassing the reproductive biology and associated behaviors is necessary to determine the influence of the reproductive cycle at many levels of the ecology and life history of *U. jamaicensis*.

6.0 Conclusions and Recommendations for Future Research

Yellow stingrays display a statistically significant increase in nocturnal activities and space utilization with intermittent movements throughout the diurnal cycle. Linearity indices and random walk simulations indicate daily movements are generally confined however, random movements occasionally occur which may involve periodic range shifts or seasonal emigration. Longer-term studies are necessary to determine the level of site fidelity and home range characteristics displayed by reproductively mature individuals and the repeatability of diel movements across multiple days.

Telemetry data also displayed evidence of habitat structure influencing the shape and direction of stingray movements. Long linear moves were characteristic of the rays distributed along a prominent eastern edge within the second reef. Regions separated by large expanses of sand (e.g. inshore surf zone or area between 2nd & 3rd reefs) characterize the hardbottom boundary and appears to be an effective barrier to

movements among the Broward County population. The more confined, circular and meandering moving individuals were generally found within the interior of the second reef (west of the prominent ledge) or within the lesser complex first reef. Yellow stingrays appear to have confined movements observed from the several animals tracked across numerous days and the relative close proximity between locations. However, this may only be a temporary situation and a continual shift of range or habitat may occur. Although home range was not fully evaluated, the individuals tracked appeared to use only a portion of their overall range during a 24 h period with evidence of multimodal behavior in the selection of core sites. Animals tracked intermittently for several days displayed more dispersed movements, while still remaining in the same general area. The use of complex structures (e.g. reef ledges, rocky overhangs and benthic biota) has also been evident during times of refuge, which have been reported to serve as a predator avoidance behavior among batoids (Cartamil *et al*, 2003).

Point count data from several projects revealed *U. jamaicensis* is quite common throughout Broward County with an approximate 13% rate of occurrence. Furthermore, analysis of the 940-point counts indicated no seasonal or monthly difference throughout all reefs for the presence of yellow stingrays. These findings establish that the local population is widespread and permanent residents along the coast of Southeast Florida and do not appear to demonstrate specific seasonal temperature preferences. However, habitat characteristics and breeding status have been suggested as potential influences on the spatial arrangement and population structure of yellow stingrays. Comparison with populations from different habitats and regions would assist in determining the extent to which bottom characteristics (habitat type) influence the distribution of *U. jamaicensis*.

Although complete gender segregation was not identified, seasonal observations during the spring did involve significantly larger proportions of females inshore. These observations appeared related to the reproductive cycle, since most females observed were in an advanced stage of gestation. Partial segregation of reproductively active females to limit competition and harassment from adult males appears more plausible than complete segregation as the reported three-month gestation period seems too brief to establish or require complete segregation of the population. Data from telemetered movements and population distribution studies need to be combined with an in depth study of the annual reproductive cycle of *U. jamaicensis* to determine the role breeding activity plays in the spatial and behavioral ecology of the population.

The use of a bottom-mounted array to obtain longer-term presence of individuals and home range behavior would provide valuable information on seasonal movement characteristics and habitat selection (Urquhart & Smith, 1986, Smith *et al*, 1998, O'Dor *et al*, 1998, Simpfendorfer & Heupel, 2002). Ongoing research with *U. halleri* in California, using several bottom-mounted data-logging monitors is obtaining excellent results (C. Lowe, personal communication).

Bottom complexity and habitat distribution need to be characterized to test for specific influences on distribution and movement patterns. Sand channels within the hardbottom community appear to be regularly used as corridors for traveling within the reef, and as refuge sites. Microhabitat selection within the reef communities is an important process that could provide considerable insight and detail into habitat parameters influencing foraging, dispersal and diel activity patterns (North & Reynolds, 1996 and Dare & Hubert, 2000).

Establishing a more intense sampling regime, repeated monthly in a localized region would provide a better understanding of the seasonal distribution among all reefs relative to onshore/offshore movements. Additionally, gender or age class segregation (social segregation within the same habitat) and the location of inshore nurseries with any subsequent ontogenetic shifts in habitat would be more clearly identified. Mating season observations to determine the timing of copulatory behavior and the influence of mating associated behavior on diel activity patterns (emphasizing diurnal movements) are required. The comparison of *U. jamaicensis* from geographically separated populations would also be beneficial to determining variations in reproductive patterns and possible implications on the underlying ecological processes (Parsons, 1993). Additional acoustic tracking studies in conjunction with habitat mapping to categorize the benthic landscape should be performed for habitat selection analyses. Animal location data with a 5 m buffer zone can be overlaid on maps of benthic composition to determine resource availability and quantify the preference or avoidance of particular habitat types (Rettie & M^{c}Loughlin, 1999). Future long-term tracking, monthly visual surveys and detailed analysis of the reproductive biology will lead to a better understanding of the life history and ecology of *U. jamaicensis*.

References

Ackerman, J.T., Kondratieff, M.C., Matern, S.A & Cech, J.J. Jr. (2000). Tidal influence on spatial dynamics of leopard sharks, *Triakis semifasciata*, in Tomales Bay, California. Envir. Biol. Fish. 58: 33-43.

Adams, N.S. Rondorf, D.W., Evans, S.D. & Kelly, J.E. (1998). Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile chinook salmon. Trans. Am. Fish. Soc. 127: 128-136.

Allen, G.R. & Robertson, D.R. (1994). *Fishes of the Tropical Eastern Pacific*. University of Hawaii Press, Honolulu, HI. pp. 34-36.

Almeida, Z.S., Nunes, J.S. & Costa, C.L. (2000). Presencia de *Urotrygon microphthalmum* (Elasmobranchii: Urolophidae) en aguas bajas de Maranhão (Brasil) y notas sobre su biología. Bol. Invest. Mar. Cost. 29: 67-72.

Arena, P.T., Jordan, L.K.B. & Spieler, R.E. (submitted). Fish assemblages on sunken-vessels and natural reefs in Southeast Florida, U.S.A.

Babel, J.S. (1967). Reproduction, life history, and ecology of the round stingray, *Urolophus halleri,* Cooper. Calif. Fish Game Bull. 137: 1-104.

Baron, R.M. (2002). The nearshore hardbottom fishes of Broward County, Florida. (M.S. Thesis) Nova Southeastern University, Dania Beach, FL 52p.

Baron, R.M., Jordan, L.K.B. & Spieler, R.E. (2004). Characterization of the marine fish assemblage associated wit the nearshore hardbottom of Broward County, FL, USA. Estuarine Coast. Shelf Sci. 60(3): 431-443.

Bearden, C.M. (1959). A life history study of the eagle ray, *Myliobatis freminvilli* LeSueur 1824, in Delaware Bay. M.S. Thesis, University of Delaware, 37p.

Bell, W.J. (1991). *Searching Behaviour: The behavioural ecology of finding resources*. Chapman & Hall, New York, NY.

Bigelow, H. B. & Schroeder, W. C. (1953). Fishes of the Western North Atlantic. sawfishes, guitarfishes, slates, ray & chimaeroids. Mem. Sears Found. Mar. Res. 1(2): 416-427.

Blaylock, R.A. (1988). Tidally-oriented movement of Cownose Rays, *Rhinoptera bonasus,* determined from Biotelemetry. (Abstr.) Annu. Meet ASIH/AES p.65.

Blaylock, R.A. (1992). Distribution, abundance, and behavior of the cownose ray, *Rhinoptera bonasus*, in lower Chesapeake Bay. (PhD. Dissertation) College of William & Mary, Williamsburg, VA. 129p.

Blaylock, R.A. (1993). Distribution and abundance of the cownose ray, *Rhinoptera bonasus*, in lower Chesapeake Bay. Estuaries 2(16): 255-263.

Böhlke, J.E. & Chaplin, C.C.G. (1993). *Fishes of the Bahamas & Adjacent Waters*. (2nd Ed.) University of Texas Press. Austin, TX. pp. 30-31.

Bohnsack, J.A. & Bannerot, S.P. (1986). A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Rep. NMFS 41.

Bolden, S.K. (2001). Using ultrasonic telemetry to determine home range of a coral-reef fish. pp. 167-188, *In*: (J.R. Sibert & J.L. Nielson, eds.) *Electronic Tagging and Tracking in Marine Fisheries*. Kluwer Academic Publishers, Netherlands.

Bray, R.N. & Hixon, M.A. (1978). Night-shocker: Predatory behavior of the Pacific electric ray (*Torpedo californica*) Science 200: 333-334.

Brown, F.A. Jr. (1961). Physiological Rhythms (Chp. 11). *In*: (T.H. Waterman, ed.) *The Physiology of Crustacea,* (Vol. II.): *sense organs, integration, and behavior.* Academic Press, New York, NY. pp. 401-430.

Brown, R.S., Cooke, S.J., Anderson, W.G. & McKinley, R.S. (1999). Evidence to challenge the "2% rule" for biotelemetry. N. Am. J. Fish. Mngt. 19: 867-871.

Bullis, H.R. & Struhsaker, P. (1961). Life history notes on the roughtail stingray, *Dasyatis centroura* (Mitchell). Copeia 1961(2): 232-234.

Campbell, B. (1951). The locomotor behavior of spinal elasmobranchs with an analysis of stinging in *Urobatis*. Copeia 1951(4): 277-284.

Capapé, C. & Zaouali, J. (1994). Distribution and reproductive biology of the blackchin guitarfish, *Rhinobatos cemiculus* (Pisces: Rhinobatidae), in Tunisian waters (Central Mediterranean). Aust. J. Mar. Freshwater Res. 45: 551-561.

Carrier, J.C. (1985). Nurse sharks (*Ginglymostoma cirratum)* of Big Pine Key, Florida (U.S.A.): An investigation of growth and movement and a comparison of the success of several types of external tags. Proc. 5th Internat. Coral Reef Conf. 6: 655-660.

Carrier, J.C., Pratt, H.L. Jr. & Martin, L.K. (1994). Group reproductive behaviors in free-living nurse sharks, *Ginglymostoma cirratum*. Copeia 1994(3): 646-656.

Cartamil, D.P., Vaudo, J.J., Lowe, C.G., Wetherbee, B.M. & Holland, K.N. (2003). Diel movement patterns of the Hawaiian stingray, *Dasyatis lata*: implications for ecological interactions between sympatric elasmobranch species. Mar. Biol. 142: 841-847.

Cavanaugh, K. & Hamlett, W.C. (1995). Subcellular organization of the epigonal gland in the yellow spotted ray, *Urolophus jamaicensis*. Notre Dame Undergraduate Research Symposium, Notre Dame, Indiana.

Chirichigno, N.F. & M^{c}Eachran, J.D. (1979). *Urolophus tumbesensis*, a new stingray from the coast of Peru (Batoidea: Urolophidae). Copeia 1979(4): 709-713.

Collazo, J.A. & Epperly, S.P. (1995). Accuracy tests for sonic telemetry studies in an estuarine environment. J. Wildlife Management. Jan. 1995. 59(1): 181-188.

Cooper, W.E., Jr. (1978). Home range criteria based on temporal stability of areal occupation. J. Theor. Biol. 73: 687-695.

Compagno, L.J.V. (1999) Checklist of living elasmobranchs. (Append.) p. 494. *In*: (W.C. Hamlett, ed.): *Sharks, Skates, and Rays: The Biology of Elasmobranch Fishes*. The John Hopkins University Press. Baltimore, MD.

Conradt, L. (1998). Measuring the degree of sexual segregation in group-living animals. J. Anim. Ecol. 67: 217-226.

Cutler, E.B. (1994). Ecology (Chp. 8). *In*: (E.B. Cutler, ed.) *The Sipuncula: their systematics, biology & evolution*. Cornell University Press, Ithaca, NY. pp. 236-248.

Dare, M.R. & Hubert, W.A. (2000). Precision and interpretation of data collected using a new measurement technique for microhabitat features at fish locations determined by radio telemetry. J. Freshwater Ecol. 15(1): 29-38.

Donald, J.A. (1988). The innervation of the gills of the stingarees *Urolophus mucosus* and *U. paucimaculatus* (Urolophidae, Elasmobranchii). Comp. Biochem. Physiol. 90C(1): 165-171.

Dubsky, P.A. (1974). Movement patterns and activity levels of fishes in Morro Bay, California as determined by ultrasonic tagging. (M.S. Thesis) California Polytechnic State University, San Luis Obispo, CA. 86p.

Dunn, K.A., M^{c}Eachran, J.D. & Honeycutt, R.L. (2003). Molecular phylogenetics of Myliobatiform fishes (Chondrichthyes: Myliobatiformes), with comments on the effects of missing data on parsimony and likelihood. Mol. Phylo. Evol. 27: 259-270.

Edwards, G.P., de Preu, N., Shakeshaft, B.J., Crealy, I.V. & Paltridge, R.M. (2001). Home range and movements of male feral cats (*Felis catus*) in a semiarid woodland environment in central Australia. Austral Ecol. 26: 93-101.

Edwards, R.R.C. (1980). Aspects of the population dynamics and ecology of the white spotted stingaree, *Urolophus paucimaculatus* Dixon, in Port Phillip Bay, Victoria. Aust. J. Mar. Freshwater Res. 31: 459-467.

Ferro, F.M. (2003). Spatial variability of the coral reef fish assemblages offshore Broward County, Florida. (M.S. Thesis) Nova Southeastern University, Dania Beach, FL. 100p.

FishBase (2004). R. Froese, & D. Pauly (eds.) World Wide Web electronic publication. www.fishbase.org version (06/2004).

Ford, R.G. (1983). Home range in a patchy environment: optimal foraging predictions. Amer. Zool. 23: 315-326.

Funicelli, N.A. (1975). Taxonomy, feeding, limiting factors, and sex ratios of *Dasyatis sabina*, *Dasyatis americana*, *Dasyatis sayi*, and *Narcine brasiliensis*. (PhD. Dissertation) University of Southern Mississippi, Hattiesburg, MS. 163p.

Garmin, S. (1885). Notes and descriptions taken from Selachians in the U.S. National Museum. Proc. U.S. Nat. Mus. 8: 39-44.

Garmin, S. (1913). *Plagiostomia*. (*Sharks, Skates, and Rays*). Mem. Mus. Comp. Zool. Harvard. Cambridge, MA.

Gilliam, D. & Sullivan, K.M. (1993). Diet and feeding habits of the southern stingray *Dasyatis americana* in the central Bahamas. Bull. Mar. Sci. 52(3): 1007-1013.

Gilliam, D.S., Dodge, R.E., Spieler, R.E., Jordan, L.K.B. & Vernacchio, J.A. (2002). Technical Report DPEP 03-04. Marine Biological Monitoring in Broward County, Florida: Year 3 Annual Report, 73p.

Gilmore, R.G. Jr., Donohoe, C.J., Cooke, D.W. & Herrema, D.J. (1981). Fishes of the Indian River Lagoon and adjacent waters, Florida. Harbor Branch Foundation, Tech. Rep. No. 41, September 1981. 64p.

Gray, A. E., Mulligan, T. J. & Hannah, R. W. (1997). Food habits, occurrence, and population structure of the bat ray, *Myliobatis californica*, in Humboldt Bay, California. Envir. Biol. Fishes. 49: 227-238.

Gruber, S.H., Nelson, D.R. & Morrissey, J.F. (1988). Patterns of activity and space utilization of lemon sharks, *Negaprion brevirostris*, in a shallow Bahamian lagoon. Bull. Mar. Sci. 43(1): 61-76.

Hamlett, W.C., Knight, D.P., Jezoir, M., Kamm, K. & Mitchell, K. (1996). Ultrastructure of the oviducal gland in the yellow spotted ray, *Urolophus jamaicensis*. Summer Meeting of the Anatomical Society of Great Britain and Ireland, Belfast, Northern Ireland, J. Anat. 188: 224-225.

Hamlett, W.C., Jezoir, M. & Spieler, R. (1999). Ultrastructure analysis of folliculogenesis in the ovary of the yellow spotted stingray, *Urolophus jamaicensis*. Ann. Anat. 181: 159-172.

Harris, S., Cresswell, W.J., Forde, P.G., Trewhella, W.J., Woollard, T. & Wray, S. (1990). Home range analysis using radio-tracking data: a review of problems and techniques particularly as applied to the study of mammals. Mamm. Rev. 20(2/3): 97-123.

Hawkins, A.D. & Urquhart, G.G. (1983). Tracking fish at sea. *In*: (A.G. MacDonald & I.G. Priede, eds.) *Experimental Biology At Sea*. Academic Press, London, England, U.K. pp. 103-166.

Herald, E.S., Schneebeli, W., Green, N. & Innes, K. (1960). Catch records for seventeen shark derbies held at Elkhorn Slough, Monterey Bay, California. Calif. Fish & Game 46(1): 59-67.

Heithaus, M.R., Dill, L.M., Marshall, G.J. & Buhleier, B. (2002). Habitat use and foraging behavior of tiger sharks (*Galeocerdo cuvier*) in a seagrass ecosystem. Mar. Biol. 140: 237-248.

Heupel, M.R. & Hueter, R.E. (2002). Importance of prey density in relation to the movement patterns of juvenile blacktip sharks (*Carcharhinus limbatus*) within a coastal nursery area. Mar. Freshwater Res. 53: 543-550.

Holland, K. Brill, R., Ferguson, S., Chang, R. & Yost, R. (1985). A small vessel technique for tracking pelagic fish. Mar. Fish. Rev. 47(4): 26-32.

Hoese, H.D. & Moore, R.H. (1998). *Fishes of the Gulf of Mexico: Texas, Louisiana, and Adjacent Waters*. (2nd Ed.) Texas A & M University Press, College Station, TX. p. 137.

Hooge, P.N. & Eichenlaub, W.M. (1997). Animal movements extension for Arcview. Alaska Biological Center, U.S.G.S., Anchorage, Alaska.

Hooge, P.N., Eichenlaub, W.M. & Solomon, E.K. (2000). Using GIS to analyze animal movements in the marine environment. 20p. (PDF file, available for download). (http://www.absc.usgs,gov/glba/gistools/index.htm).

Hopkins, T.E. & Cech, J.J. Jr. (1994). Effect of temperature on oxygen consumption of the bat ray, *Myliobatis californica* (Chondrichthyes, Myliobatidae). Copeia 1994(2): 529-532.

Humann, P. (2002). Reef fish identification: Florida, Caribbean, Bahamas. (3rd Ed.) (N. Deloach, ed.). New World Publications. Jacksonville, FL. pp. 456-457.

Ireland, L.C. & Kanwisher, J.W. (1978). Underwater acoustic biotelemetry: procedures for obtaining information on the behavior and physiology of free-swimming aquatic animals in their natural environments. pp. 341-379, *In*: (D.I. Mostofsky, ed.) *The behavior of fish and other aquatic animals*. Academic Press, New York, NY.

Iwasa, Y., Higashi, M. & Yamamura, N. (1981). Prey distribution as a factor determining the choice of optimal foraging strategy. Amer. Naturalist 117(5): 710-723.

Jaap, W.C. (1984). The ecology of the South Florida coral reefs: a community profile (Chp. 2.). U.S. Fish and Wildlife Services. FWS/ OBS-82/08, 138p.

Jezoir, M.R. & Hamlett, W.C. (1994). Ultrastructure of the uterus and shell gland in the yellow spotted ray: a model for reproductive toxicology. Notre Dame Undergraduate Research Symposium, Univ. Notre Dame, Notre Dame, Indiana. Notre Dame Science Quarterly. 23(4): 9-11.

Johnson, A.R., Wiens, J.A., Milne, B.T. & Crist, T.O. (1992). Animal movements and population dynamics in heterogeneous landscapes. Land. Ecol. 7(1): 63-75.

Johnson, R.H. & Nelson, D.R. (1978). Copulation and possible olfaction-mediated pair formation in two carcharhinid sharks. Copeia 1978(3): 539-542.

Jordan, L.K.B. & Spieler, R.E. (submitted). Implications of natural variation in fish assemblages to coral reef management.

Kanwisher, J., Lawson K. & Sundnes, G. (1974). Acoustic telemetry from fish. Fish. Bull. 72(2): 251-255.

Klimley, A.P. (1987). The determinants of sexual segregation in the scalloped hammerhead shark, *Sphyrna lewini*. Envir. Biol. Fish. 18: 27-40.

LaMarca, M.J. (1961). The anatomy of the reproductive system of the yellow stingray, *Urolophus jamaicensis* (Cuvier). (PhD. Dissertation) Cornell University, Ithaca, NY. 147p.

LaMarca, M.J. (1963). The embryonic spiracular fold of the yellow stingray *Urolophus jamaicensis*. Copeia. 1963(3): 593-595.

LaMarca, M.J. (1964). Functional anatomy of the clasper and clasper gland of the yellow stingray, *Urolophus jamaicensis*. J. Morph. 114: 303-324.

López, M.I. & Bussing, W.A. (1998). *Urotrygon cimar*, a new eastern Pacific stingray (Pisces: Urolophidae). Rev. Biol. Trop. 46(suppl.6): 271-277.

Lovejoy, N.R. (1996). Systematics of myliobatoid elasmobranchs: with emphasis on the phylogeny and historical biogeography of neotropical freshwater stingrays (Potamotrygonidae: Rajiformes). Zool. J. Linn. Soc. 117: 207-257.

Lowe, C.G., Bray, R.N. & Nelson, D.R. (1989). Field studies on the behavior of the Pacific Electric Ray, *Torpedo californica*: a preliminary report. (Abstr.) Annu. Meet. ASIH/AES, San Francisco, CA, p.112.

Matern, S.A., Cech, J.J. Jr. & Hopkins, T.E. (2000). Diel movements of bat rays, *Myliobatus californica*, in Tomales Bay, California: evidence for behavioural thermoregulation? Environ. Biol. Fish. 58(2): 173-182.

M^{c}Eachran, J.D. & Musick, J.A. (1975). Distribution and relative abundance of seven species of skates (PISCES: Rajidae) which occur between Nova Scotia and Cape Hatteras. Fish. Bull. 73(1): 110-136.

M^{c}Eachran, J.D. & Fechhelm, (1994). Fishes of the Gulf of Mexico: (Volume 1) *Myxiniformes* to *Gasterosteiformes*. University of Texas Press, Austin, TX. pp. 183-184.

M^{c}Eachran, J.D., Dunn, K.A. & Miyake, T. (1996). Interrelationships of the batoid fishes (Chondrichthyes: Batoidea). *In*: (M.L.J. Stiaggny, L.R. Parenti & G.D. Johnson, eds.) *Interrelationships of Fishes*. Academic Press, San Diego, CA. pp. 63-84.

M^{c}Kibben, J.N. & Nelson, D.R. (1986). Patterns of movement and grouping of gray reef sharks, *Carcharhinus amblyrhynchos*, at Enewetak, Marshall Islands. Bull. Mar. Sci. 38(1): 89-110.

Menni, R.C. & Stehmann, F.W. (2000). Distribution, environment and biology of batoid fishes off Argentina, Uruguay and Brazil: a review. Rev. Mus. Argent. Cienc. Nat. (Nueva Ser.). 2(1): 69-109.

Miyake, T. (1988). The systematics of the genus *Urotrygon* with comments on the interrelationships within Urolophidae (Chondrichthyes, Myliobatiformes). (PhD, Dissertation), Texas A & M University, College Station, TX. 491p.

Miyake, T. & M^{c}Eachran, J.D. (1986). Taxonomy of the stingray genus *Urotrygon* (Myliobatiformes: Urolophidae): Preliminary results based on external morphology. *In*: (T. Uyeno, R. Arai, T. Taniuchi & K. Matsuura, eds.) *Indo-Pacific Fish Biology*: Proc. 2nd Internat. Conf. Indo-Pac. Fish. Tokyo, Japan. pp.291-302.

Miyake, T. & M^{c}Eachran, J.D. (1988). Three new species of the stingray genus *Urotrygon* (Myliobatiformes: Urolophidae) from the Eastern Pacific. Bull. Mar. Sci. 42(3): 366-375.

Morrissey, J.F. & Gruber, S.H. (1993a). Home range of juvenile lemon sharks *Negaprion brevirostris*. Copeia 1993(2): 425-434.

Morrissey, J.F. & Gruber, S.H. (1993b). Habitat selection by juvenile lemon sharks, *Negaprion brevirostris*. Envir. Biol. Fish. 38: 311-319.

Moyle, P.B. & Cech, J.J. Jr. (2000). *Fishes an Introduction to Ichthyology*. (Chp.15): sharks, rays and chimaeras. (4th Ed.). Prentice-Hall. Upper Saddle River, NJ. pp. 219-232.

Nelson, D.R. (1997). Telemetry studies of sharks: a review, with applications in resource management. pp. 239-256, *In*: (H. L. Pratt, S. H. Gruber & T. Taniuchi, eds.) *Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and the status of the Fisheries*. NOAA technical Report NMFS 90, August. Springfield, VA.

Nelson, D.R. (1978). Telemetering techniques for the study of free-ranging sharks. *In*: (E. Hodgson & R. Mathewson, eds.) *Sensory Biology of Sharks, Skates, and Rays*. Office Naval Research, Arlington, VA. pp. 419-482.

Nordell, S.E. (1990). The courtship and mating behavior of the round stingray, *Urolophus halleri*. (M.S. Thesis) University of Arizona, 47p.

Nordell, S.E. (1994). Observations of the mating behavior and dentition of the round stingray, *Urolophus halleri*. Envir. Biol. Fishes. 39: 219-229.

North, M.P. & Reynolds, J.H. (1996). Microhabitat analysis using radiotelemetry and polytomous logistic regression. J. Wildl. Manag. 60(3): 639-653.

O'Dor, R.K., Andrade, Y., Webber, D.M., Sauer, W.H.H., Roberts, M.J., Smale, M.J. & Voegeli, F.M. (1998). Applications and performance of radio-acoustic positioning and telemetry (RAPT) systems. Hydrobiologia 371/372: 1-8.

Olson, K.R., Forster, M.E., Bushnell, P.G. & Duff, D.W. (2000). Spontaneous contractions in elasmobranch vessels *in vitro*. J. Exp. Zool. 286: 606-614.

Parsons, G.R. (1993). Geographic variation in reproduction between two populations of the bonnethead shark, *Sphyrna tiburo*. Envir. Biol. Fish. 38: 25-35.

Pittenger, G.G. (1984). Movements, distribution, feeding, and growth of the Pacific Angel Shark, *Squatina californica*, at Catalina Island, California. (M.S. Thesis) California State University, Long Beach, CA. 83p.

Phleger, C.F. (1988). Bone lipids of Jamaican reef fishes. Comp. Biochem. Physiol. 90B(2): 279-283.

Platell, M.E., Potter, I.C. & Clarke, K.R. (1998). Resource partitioning by four species of elasmobranchs (Batoidea: Urolophidae) in coastal waters of temperate Australia. Mar. Biol. 131: 719-734.

Priede, I.G. (1986). An introduction to wildlife telemetry. pp. 4-24, *In:* (I.G. Priede & S.M. Swift, eds.) *Wildlife Telemetry: Remote Monitoring and Tracking of Animals*. Ellis Horwood series in environmental management, science and technology.

Pyke, G.H., Pulliam, H.R. & Charnov, E.L. (1977). Optimal foraging: a selective review of theory and tests. Quart. Rev. Biol. 52(2): 137-154.

Quinn, T.P. (1996). Diet and seasonal feeding habits of the yellow stingray, *Urolophus jamaicensis*. (M.S. Thesis) Nova Southeastern University, Dania Beach, FL 45p.

Rabinowitz, A. (1990). Notes on the behavior and movements of leopard cats, *Felis bengalensis*, in a dry tropical forest mosaic in Thailand. Biotropica 22(4): 397-403.

Rabinowitz, A.R. & Nottingham, B.G. Jr. (1986). Ecology and behaviour of the Jaguar (*Panthera onca*) in Belize, Central America. J. Zool. Lond. 210(A): 149-159.

Randall, J.E. (1968). *Caribbean Reef Fishes*. (1st Ed.) T. F. H. Publications, Neptune City, NJ.

Reef Environmental Education Foundation (REEF) (2003). Regional fish census data (*Urobatis jamaicensis*) available on-line. http://www.reef.org

Reese, E.S. (1978). The study of space-related behavior in aquatic animals: special problems and selected examples. *In*: (E. R. Reese & F. J. Lighter, eds.) *Contrasts in Behavior*. Wiley-Interscience, New York, NY. pp. 347-374.

Rettie, W.J. & McLoughlin, P.D. (1999). Overcoming radiotelemetry bias in habitat-selection studies. Can. J. Zool. 77: 1175-1184.

Robins, C.R., Ray, G.C. & Douglass, J. (1986). *Peterson Field Guide: Atlantic coast fishes, North America*. p.42.

Rodríguez-Romero, J., Abitia-Cárdenas, L.A., Galván-Magaña, F., Gutiérrez-Sánchez, F.J., Aguilar-Palomino, B. & Arvizú-Martínez, J. (1998). Ecology of fish communities from the soft bottoms of Bahía Concepción, México. Arch. Fish. Mar. Res. 46(1): 61-76.

Rosa, R.S. (1985). A systematic revision of the South American freshwater stingrays (Chondrichthyes: Potamotrygonidae). (PhD. Dissertation) College of William & Mary, Williamsburg, VA.

Rosa, R.S., Castello, H.P. & Thorson, T.B. (1987). *Plesiotrygon iwamae*, a new genus and species of neotropical freshwater stingray (Chondrichthyes: Potamotrygonidae). Copeia 1987(2): 447-458.

Rosenberger, L.J. (2001). Phylogenetics relationships within the stingray Genus *Dasyatis* (Chondrichthyes: Dasyatidae). Copeia 2001(3): 615-627.

Rudloe, A. (1989). Habitat preferences, movement, size frequency patterns and reproductive seasonality of the lesser electric ray, *Narcine brasiliensis*. Northeast Gulf Sci. 10(2): 103-112.

Russell, F.E. (1953). Stingray injuries, a review and discussion of their treatment. Am. J. M Sci. 226(2): 611-622.

Russell, F.E. & Van Harreveld, A. (1954). Cardiovascular effects of the venom of the round stingray, *Urobatis halleri*. Arch. Int. de Phys. 57(3): 322-333.

Russell, F.E. (1955). Multiple caudal spines in the round stingray, *Urobatis halleri*. Cal. Fish & Game. 41(3): 213-217.

Sage, M., Jackson, R.G., Klesch, W.L. & de Vlaming, V.L. (1972). Growth and seasonal distribution on the elasmobranch, *Dasyatis Sabina*. Contr. Mar. Sci.. 16: 71-74.

Schmid, T.H. (1984). Age, growth, and movement patterns of the Atlantic stingray, Dasyatis sabina, in a Florida coastal lagoon system. (M.S. Thesis) University Central Florida, Orlando, FL. 85p.

Schwartz, F. S. & Dahlberg, M. D. (1978). Biology and ecology of the Atlantic stingray, *Dasyatis sabina*, in North Carolina and Georgia. Northeast Gulf Sci. 2(1): 1-23.

Seaman, D.E. and Powell, R.A. (1996). An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology. 77(7): 2075-2085.

Sherman, R.L. (1998). Fine structure of the gill vasculature of the yellow stingray (*Urolophus jamaicensis*). (M.S. Thesis) Nova Southeastern University, Dania Beach, FL 22p.

Sherman, R.L. & Gilliam, D.S. (1996). Hepato-somatic indices and lifestyles in some batoid elasmobranchs. Fla. Sci. 59(4): 275-278.

Sherman, R.L. & Spieler, R.E. (1998). Examination of gill vasculature of yellow stingray, *Urolophus jamaicensis* (Urolophidae), by SEM observations of resin casts. Ital. J. Zool. 65(suppl.): 431-434.

Silliman, W.R. & Gruber, S.H. (1999). Behavioral biology of the spotted eagle ray, *Aetobatus narinari*. Bahamas J. Sci. 7(1): 13-20.

Simpfendorfer, C.A. & Heupel, M.R. (2002). Estimation of short-term centers of activity from an array of omnidirectional hydrophones, and its use in studying animal behavior. Can. J. Fish. Aqua. Sci. 59: 23-32.

Sims, D., Nash, J.P. & Morritt, D. (2001). Movements and activity of male and female dogfish in a tidal sea lough: alternative behavioral strategies and apparent sexual segregation. Mar. Biol. 139: 1165-1175.

Siniff, D.B. & Tester, J.R. (1965). Aspects of animal movement and home range data obtained by telemetry. *Transactions of the North American Wildlife and Natural Resources Conference.* 30: 379-392.

Smith, J.W. & Merriner, J.V. (1986). Observations on the reproductive biology of the cownose ray, *Rhinoptera bonasus*, in Chesapeake Bay. Fish. Bull. 84(4): 871-877.

Smith, J.W. & Merriner, J.V. (1987). Age and growth, movements and distribution of the cownose ray, *Rhinoptera bonasus*, in Chesapeake Bay. Estuaries 10: 153-164.

Smith, G.W., Urquhart, G.G., MacLennan, D.N. & Sarno, B. (1998). A comparison of theoretical estimates of the errors associated with ultrasonic tracking using a fixed hydrophone array and field measurements. Hydrobiologia, 371/372: 9-17.

Snelson, F. F. Jr., Williams-Hooper, S. E. & Schmid, T. H. (1988). Reproduction and ecology of the Atlantic stingray, *Dasyatis sabina*, in Florida coastal lagoons. Copeia 1988: 729-739.

Snelson, F. F. Jr., Williams-Hooper, S. E. & Schmid, T. H. (1989). Biology of the bluntnose stingray, *Dasyatis sayi*, in Florida coastal lagoons. Bull. Mar. Sci. 45(1): 15-25.

Sokal, R.R. & Rohlf, F.J. (1995). *Biometry: The Principles and Practice of Statistics in Biological Research*. (3rd Ed.) W.H. Freeman and Company, New York, NY, USA.

Sonotronics Product Catalog (2000). Tuscon, AZ.

Spencer, S.R., Cameron, G.N. & Swihart, R.K. (1990). Operationally defining home range: temporal dependence exhibited by hispid cotton rats. Ecology 71(5): 1817-1822.

Standora, E.A. & Nelson, D.R. (1977). A telemetric study of the behavior of free-swimming pacific angel sharks, *Squatina californica*. Bull. S. Calif. Acad. Sci. 76: 193-201.

Stasko, A.B. & Pincock, D.G. (1977). Review of underwater biotelemetry, with emphasis on ultrasonic techniques. J. Fish. Res. Board Can. 34: 1262-1285.

Strong, W.R. (1989). Behavioral ecology of horn sharks, *Heterodontus francisci*, at Santa Catalina Island, California, with emphasis on patterns of space utilization. (M.S. Thesis) California State University, Long Beach, CA. 252p.

Struhsaker, P. (1969). Observations on the biology and distribution of the thorny stingray, *Dasyatis centroura* (PISCES: Dasyatidae). Bull. Mar. Sci. 19: 456-481.

Sulikowski, J. (1996). A preliminary study of the population density, size distribution, age and growth of the stingray, *Urolophus jamaicensis*, in Southeastern, Florida. (M.S. Thesis) Nova Southeastern University, Dania Beach, FL 72p.

Sulikowski, J.A. & Maginniss, L.A. (2001). Effects of environmental dilution on body fluid regulation in the yellow stingray, *Urolophus jamaicensis*. Comp. Biochem. Physiol. (Part A.) 128: 223-232.

Taulman, J.F. & Seaman, D.E. (2000). Assessing southern flying squirrel, *Glaucomys volans*, habitat selection with kernel home range estimation and GIS. Can. Field Naturalist. 114(4): 591-600.

Talent, L.G. (1985). The occurrence, seasonal distribution and reproductive condition of elasmobranch fishes in Elkhorn Slough, California. Calif. Fish Game Bull. 71: 210-219.

Teaf, C.M. (1980). A study of the tidally-oriented movements of the Atlantic stingray, *Dasyatis sabina* (LeSueur) in Apalachee Bay, Florida. (M.S. Thesis), Florida State University, Tallahassee, FL. 48p.

Tester, J.R. & Siniff, D.B. (1965). Aspects of animal movement and home range data obtained by telemetry. *Transactions of the North American Wildlife and Natural Resources Conference.* 30: 379-392.

Thorson, T.B. (1983). Observations on the morphology, ecology and life history of the euryhaline stingray, *Dasyatis guttata* (Bloch and Schneider) 1801. Acta. Biol. Venez., 11(4): 95-125.

Thorson, T.B., Langhammer, J.K. & Oetinger, M.I. (1983). Reproduction and development of the South American freshwater stingrays, *Potamotrygon circularis* and *P. motoro*. Environ. Biol. Fish. 9(1): 3-24.

Thorstad, E.B., Økland, F. & Heggberget, T.G. (2001). Are long term negative effects from external tags underestimated? Fouling of an externally attached telemetry transmitter. J. Fish Biol. 59: 1092-1094.

Tricas, T.C., Michael, S.W. & Sisneros, J.A. (1995). Electrosensory optimization to conspecific phasic signals for mating. Neuroscience Lett. 202: 129-132.

Urquhart, G.G. & Smith, G.W. (1986). Recent developments of a fixed array system for monitoring movements of aquatic animals. pp. 342-353**,** *In*: (I.G. Priede, Ed.) *Wildlife Telemetry: Remote Monitoring and Tracking of Animals*. Ellis Horwood series in environmental management, science and technology.

Valdez-González, C., Aguilar-Palomino, B. & Hernández-Vázquez, S. (2001). Feeding habits of the round stingray Urobatis halleri (Cooper, 1863) (Chondrichthyes: Urolophidae) from the continental shelf of Jalisco and Colima, Mexico. Ciencas Marinas 27(1): 91-104.

Villavicencio-Garayzar, C.J. (1995). Reproductive biology of the banded guitarfish, *Zapterix exasperata* (PISCES: Rhinobatidae), in Bahía Almejas, Baja California Sur, Mexico. Ciencas Marinas 21(2): 141-153.

Walker, B.K. & Sherman, R.L. (2001). Gross brain morphology in the yellow stingray, *Urobatis jamaicensis*. Fla. Scient. 64(4): 246-249.

White, G.C. & Garrott, R.A. (1990). Home range estimation. (Chp. 7.) *In*: (G.C. White & R.A. Garrott, eds.) *Analysis of Wildlife Radio-tracking Data*. Academic Press, San Diego, CA. pp. 145-182.

Winter, J.D. & Ross, M.J. (1982). Methods in analyzing fish habitat utilization from telemetry data. *In*: (N. Armatrout, ed.) *Proc. Symp. Acquisition and Utilization of Aquatic habitat inventory Information*. Amer. Fish. Soc., West. Div. pp. 273-279.

Wolcott, T.G. (1995). New options in physiological and behavioural ecology through multichannel telemetry. J. Exp. Mar. Biol. Eco. 193(1-2): 257-275.

Worton, B.J. (1987). A review of models of home range for animal movement. Ecol. Modell. 38: 277-298.

Worton, B.J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. Ecology. 70(1): 164-168.

Yañez-Arancibia, A. & Amezcua-Linares, F. (1979). Ecologia de *Urolophus jamaicensis* (Cuvier) en laguna de terminos un sistema estuarino del golfo sur del golfo de mexico. (PISCES: Urolophidae). An. Centro Cienc. Del Mar Y Limnol., Univ. Nal. Auton. Mexico, 6(2): 123-136.

Yano, K.T., Takashi, I.O., Hirofumi, S. & Takeharu, K. (2000). Telemetry studies on the movements of the manta ray, Manta birostris, at the Yaeyama Islands, Okinawa, Japan. (Abstr.) p.381, AES/ASIH Joint Conference, La Paz, B.C.S., Mexico, June 14-17, 2000.

Young, R.F. (1993). Observation of the mating behavior of the yellow stingray, *Urolophus jamaicensis*. Copeia 1993(3): 879-880.

Zamparo, D., Brooks, D.R. & Barriga, R. (1999). *Pararhinebothroides hobergi* N. Gen. Sp. (Eucestoda: Tetraphyllidea) in *Urobatis tumbesensis* (Chondrichthyes: Myliobatiformes) from coastal Ecuador. J. Parisitol. 85(3): 534-539.

Zar, J.H. (1996). *Biostatistical Analysis* (3rd Ed.) Prentice Hall, Inc., Upper Saddle River, NJ.

Zeller, D.K. (1997). Home range and activity patterns of the coral trout *Plectropomus leopardus* (Serranidae). Mar. Ecol. Prog. Ser. 154: 65-77.

Appendices

Appendix A. Variation in reported maximum size of *Urobatis jamaicensis*, from the most widely used references. Approximations of total length (TL) are provided when only disk width (DW) was reported.

Reference	Reported Maximum Size
Fowler (1945)	305-355mm DW (~610-700mmTL)
Bigelow & Schroeder (1953)	455mm TL
Robins *et al* (1986)	660mm TL
Hoese & Moore (1988)	300mm DW (~650mm TL)
Böhlke & Chaplin (1993)	26 or 27 inches TL (~650-680mm TL)
Lieske & Meyers (1994)	760mm TL
Smith (1997)	14 inches DW (350mm) or (~700mm TL)
Randall (1996)	less than 2.5 feet TL (~750mm TL)
M^{c}Eachran & Fechhelm (1998)	700mm TL
Allen (1999)	26 inches TL (~650mm TL)
Humann (2002)	15 inches DW (375mm) or (~750mm TL)

Appendix B. Sixteen Amphi-American Urolophidae species from the Western Atlantic and Eastern Pacific Continental shelves. (Miyake &McEachran, 1986, Compagno, 1999, FISHBASE, 2004).

Genus *Urobatis* (Garmin, 1913). Short-tail round stingrays.

Urobatis conscentricus (Osburn & Nichols, 1916). Bull's-eye stingray.

Gulf of California and Mexico, **Eastern Pacific**. 475mm TL

Urobatis halleri (Cooper, 1863). Round stingray.

Northern California to Panama, **Eastern Pacific**. 580mm TL

Urobatis jamaicensis (Cuvier, 1817). Yellow stingray

South Florida, Texas, Gulf of Mexico, Caribbean to Northern Brazil. **Western Atlantic**. 760mm TL

Urobatis maculatus (Garmin, 1913). Cortez round stingray

Southern Baja California, Mexico and Gulf of California. **Eastern Pacific**. 420mm TL

Urobatis marmoratus (Phillipi, 1893). Chilean round stingray

Chile. **Southeastern Pacific**. Size N/A

Urobatis tumbesensis (Chirichigno & M^{c}Eachran, 1979). Tumbes round stingray

Peru. **Southeastern Pacific**. 404mm TL

Genus *Urotrygon* (Gill, 1864). Long-tail round stingrays.

Urotrygon aspidura (Jordan & Gilbert, 1882). Roughtail round stingray.

Panama to Peru. **Eastern Pacific**. 421mm TL

Urotrygon chilensis (Gunther, 1871). Thorny round stingray

Gulf of California to Peru and Chile. **Eastern Pacific**. 419mm TL

Urotrygon cimar (Lopez & Bussing, 1998).

Nicaragua to Costa Rica. **Eastern Pacific**. 382mm TL

Urotrygon microphthalmum (Delsman, 1941). Smalleyed round stingray

Northern Brazil and Venezuela. **Western Atlantic**. 300mm TL

Urotrygon munda (Gill, 1863). Shortfin round stingray.

El Salvador and Panama. **Eastern Pacific**. 288mm TL

Urotrygon nana (Miyake & M^{c}Eachran, 1988). Dwarf round stingray

Central and South Mexico and Costa Rica. **Eastern Pacific**. 250mm TL

Urotrygon reticulata (Miyake & M^{c}Eachran, 1988). Reticulate round stingray

Panama. **Eastern Pacific**. 241mm TL

Urotrygon rogersi (Jordan & Starks, 1895). Lined round stingray

Gulf of California to Ecuador. **Eastern Pacific**. 462mm TL

Urotrygon simulatrix (Miyake and M^{c}Eachran, 1988). Stellate round stingray

Gulf of Panama. **Eastern Pacific**. 267mm TL

Urotrygon venezuelae (Schultz, 1949). Venezuelan round stingray

Columbia and Venezuela. **Western Atlantic**. 286mm TL

Appendix C. Batoid telemetry tracking studies* conducted to date or on-going research. C: represents hours of Continuous tracking and I: represents days of Intermittent tracking (both values indicate the maximum duration recorded).

Species	*n*	Maximum Duration	Method	Author
Aetobatus narinari	17	96h C, 93d I	Acoustic Telemetry (Manual)	Silliman & Gruber, 1999
Dasyatis americana	N/A	Preliminary	Acoustic Telemetry (Manual)	Snelson *et al*, 1988
	N/A	On-going	Acoustic Telemetry (Manual)	Corcoran, ongoing
Dasyatis lata	7	50h C	Acoustic Telemetry (Manual)	Cartamil *et al*, 2003
	N/A	On-going	Bottom Data-Logging Array	Crow, ongoing
Dasyatis fluviorum	N/A	Ongoing	Acoustic Telemetry (Manual)	Pierce, ongoing
Dasyatis kuhlii	N/A	On-going	Acoustic Telemetry (Manual)	Pierce, ongoing
Manta birostris	6	Diel Tracks	Acoustic Telemetry (Manual)	Yano *et al*, 2000
	6	Preliminary	Acoustic Telemetry (Manual)	Clark, 2002
Myliobatis californica	1	23.25h C	Acoustic Telemetry (Manual)	Dubsky, 1974
	N/A	Preliminary	Acoustic Telemetry (Manual)	Hopkins & Cech, 1994
	11	13mo I	Acoustic Telemetry (Manual)	Matern *et al*, 1999
Rhinobatis productus	1	16h C	Acoustic Telemetry (Manual)	Dubsky, 1974
Rhinoptera bonasus	6	13.5h C	Acoustic/Radio Telemetry (Manual)	Blaylock, 1988
Torpedo californica	N/A	Preliminary	Acoustic Telemetry (Manual)	Bray & Hixon, 1978
	N/A	Preliminary	Acoustic Telemetry (Manual)	Lowe *et al*, 1989
Urobatis halleri	N/A	On-going	Bottom Data-Logging Acoustic Array Telemetry (Manual)	Vaudo & Lowe, ongoing
Urobatis jamaicensis	17	28h C, 13d I	Acoustic Telemetry (Manual)	Fahy, 2004

One additional species, ***Dasyatis sabina*** was visually tracked with balloon float tags for short durations during daytime periods only (Teaf, 1980).

Appendix D. Summary table for seasonal distribution studies of batoids and the environmental influence considered responsible for observed movements.

Species	Location	Influence	Reference
Dasyatis centroura	Eastern States, USA	Temperature	Bullis & Sthuhsaker (1961)
	Southeastern States, USA	Temperature	Struhsaker (1969)
	East Central Florida, USA	Temperature	Reed & Gilmore (1981)
Dasyatis say	Gulf of Mexico, Mississippi, USA	Temperature	Funicelli (1975)
	Indian River Lagoon, Florida, USA	**Permanent Resident**	Schmid *et al* (1988)
	Indian River Lagoon, Florida, USA	Salinity	Snelson *et al* (1989)
Dasyatis americana	Gulf of Mexico, Mississippi, USA	Temperature	Funicelli (1975)
	Indian River Lagoon, Florida, USA	*Temperature/Salinity*	Snelson & Williams (1981)
Dasyatis sabina	Gulf of Mexico, Texas, USA	Temperature	Sage *et al* (1972)
	Gulf of Mexico, Mississippi, USA	Salinity	Funicelli (1975)
	North Carolina & Georgia, USA	Temperature	Schwartz & Dahlberg (1978)
	Indian River Lagoon, Florida, USA	Temperature	Schmid (1984)
	Indian River Lagoon, Florida, USA	Temperature	Snelson *et al* (1988)
Dasyatis guttata	Costa Rica & Venezuela	Temperature	Thorson (1983)
Myliobatis californica	Tomales Bay, California, USA	Temperature	Ridge (1963)
	Elkhorn Slough, California, USA	Temperature	Talent (1985)
	Elkhorn Slough, California, USA	Temperature	Martin & Cailliet (1988)
	Tomales Bay, California, USA	Salinity	Hopkins (1993)
	Humboldt Bay, California, USA	*Temperature/Salinity*	Gray *et al* (1997)
Myliobatis freminvilli	Deleware Bay, USA	Temperature	Bearden (1965)
Aetobatus narinari	Indian River Lagoon, Florida, USA	Temperature	Schmid *et al* (1988)
	Bimini, Bahamas	Temperature	Silliman & Gruber (1999)
Gymnura micrura	Deleware Bay, USA	Temperature	Daiber & Booth (1960)
Gymnura altavela	Deleware Bay, USA	Temperature	Daiber & Booth (1960)
Rhinoptera bonasus	Chesapeake Bay, USA	Temperature	Schwartz (1965)
	Chesapeake Bay, USA	Temperature	Smith & Merriner (1986)
	Chesapeake Bay, USA	Temperature	Smith & Merriner (1987)
	Northern Gulf of Mexico	Temperature	Rogers *et al* (1990)
	Chesapeake Bay, USA	Temperature	Blaylock (1993)
Narcine brasiliensis	Gulf of Mexico, Mississippi, USA	Temperature	Funicelli (1975)
	Gulf of Mexico, Mississippi, USA	Temperature	Rudloe (1989)
Urobatis halleri	Southern California, USA	Temperature	Babel (1967)

Appendix E. Individual movement description and summary of 24h diel tracks, telemetry movement paths and KUD contours with additional discussion on (9) animals tracked for less than 24h.

#1. 1-98-294: (Preliminary Track) a male stingray was captured at 1138h (01/24/98) actively swimming over hardbottom of the 1st reef in water 5.5 m deep. The ray was monitored along with two other animals for nearly four hours and a single direct observation confirmed minimal movement of ~ 6 m away from the capture site. Several other rays were observed in close proximity to the telemetered animals upon release. Poor weather conditions prohibited tracking until 01/27/98 and stingray #1 was relocated at 1730h within the general area of the capture site. Poor weather conditions persisted for over a week and stingray #1 was relocated a final time on 02/05/98 at 1840h ~100m east of the previous location.

#2. 1-98-555: (Preliminary Track) a male stingray was captured at 1229h (01/24/98) resting on hardbottom of the 1st reef in water 5.5 m deep. The ray was also monitored for several hours, displaying a minimal movement of ~30 feet (9.1m) from initial location. The signal for stingray #2 was also relocated in the general area at 1800 on (01/27/98). The final position for stingray #2 was also recorded ~100m east of the previous region and 20-25m south of stingray #1 at 1840 on (02/05/98).

#3. 1-98-442: (Preliminary Track) the female stingray was captured at 1212 (01/24/98) resting on hardbottom of the 1st reef in water 18 feet (5.5m) deep. Divers were unable to confirm movements through direct observations, however telemetry determined only minimal movements resembling both of the male stingrays. Stingray #3 was relocated at 1750 (01/27/98) also in the near vicinity of the capture site. Unlike the two previous animals, stingray #3 was not relocated a third time (searched for two hours) and only demonstrated site fixity for several days. Unsuccessful attempts on two separate days were conducted to relocate all animals before terminating efforts. Possibly in close proximity but signal interference did not permit successful relocation.

A noteworthy observation can be viewed from the three-overlaid minimum complex polygon (MCP) contours, which enclose the total space utilized within all marked locations. Both male stingrays 1-98-294 (white) and 1-98-555 (purple) activity spaces barely overlap, whereas the female 1-98-442 (yellow) MCP is situated between both males with partial overlap of their respective ranges (**Figure A**).

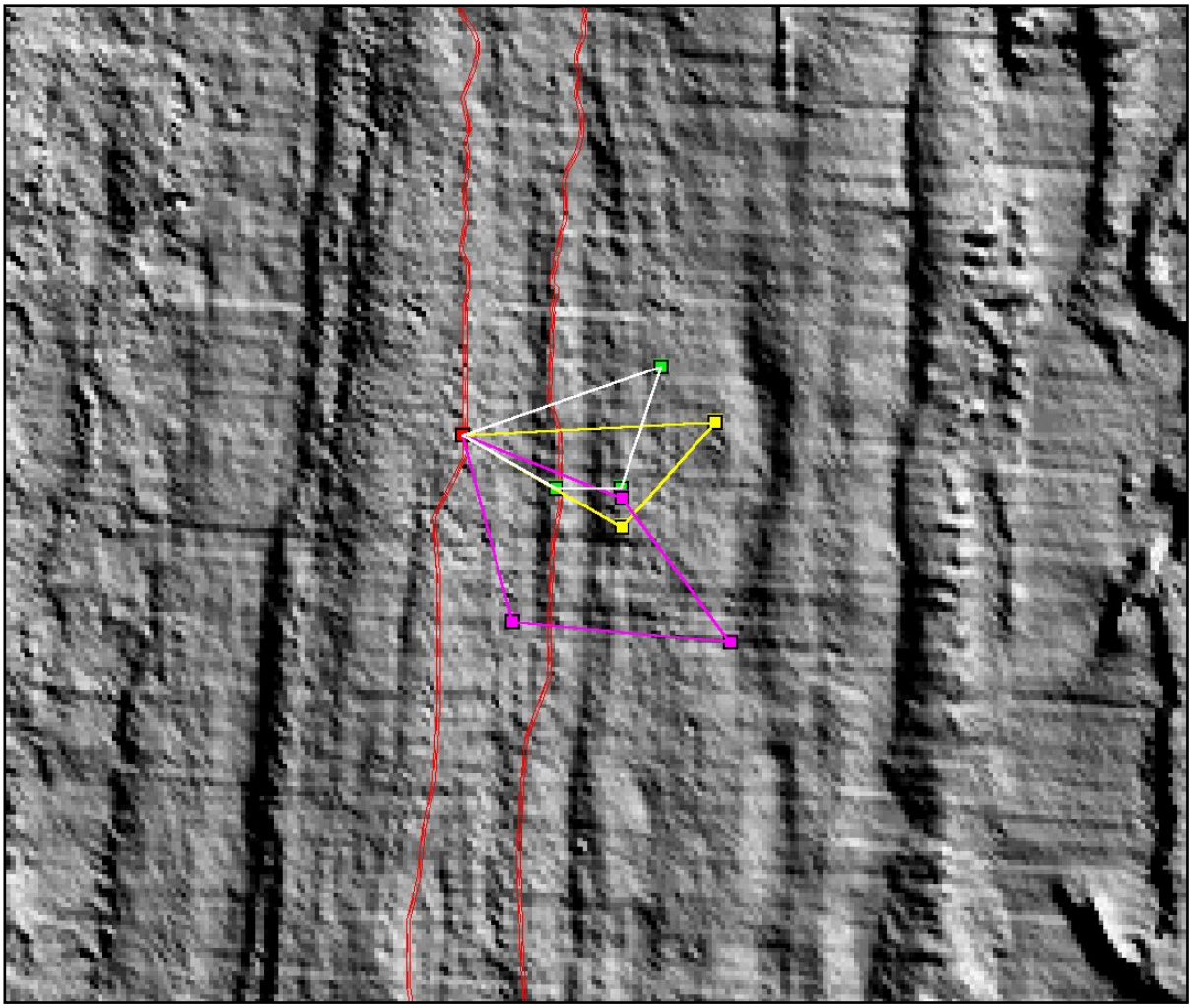


Figure A. **January 1998** preliminary tracks, LADS image with minimum complex polygons (MCP) contours. Red square represents the common capture area for all three rays (#'s 1, 2, 3) and is situated on the eastern edge of the first reef. Green squares depict (locations) and white line (MCP) for 1-98-294, pink squares depict (locations) and pink line (MCP) for 1-98-555 and yellow squares depict (locations) and yellow line (MCP) for 1-98-294. The red lines represent the boundaries of the transitional area between the 1st and 2nd reefs where substrate varies from a sandy flat with patchy hardbottom to a more consistent rubble zone with less obvious differentiation between reef edges.

#4. (Preliminary Track) 3-99-645, a male stingray, was captured at 1019h (03/15/99) while resting uncovered on sand next to a prominent ledge along the interior of the second reef in water 8.3 m deep. Surgery was conducted the following morning in the lab and the animal was released two hours later in the vicinity of the capture site at 1000 hours (03/16/99). Stingray #4 immediately moved off to the east and was eventually relocated ~200m SE from the release point. Continuous tracking lasted only 5.75 hours (due to weather conditions) and observed movements along the eastern edge of the second reef were minimal. Persisting weather conditions postponed attempts to recapture stingray #4 and collect the transmitter for several days. The stingray was eventually recaptured ~335m NW of the previous position in water 8.8 m deep, fully buried with only the tag exposed in an area of patchy hardbottom (03/19/99). Note the move back off the reef crest to within a closer proximity of the original capture site (may indicate fidelity to a specific site or habitat preference) (**Figure B**).

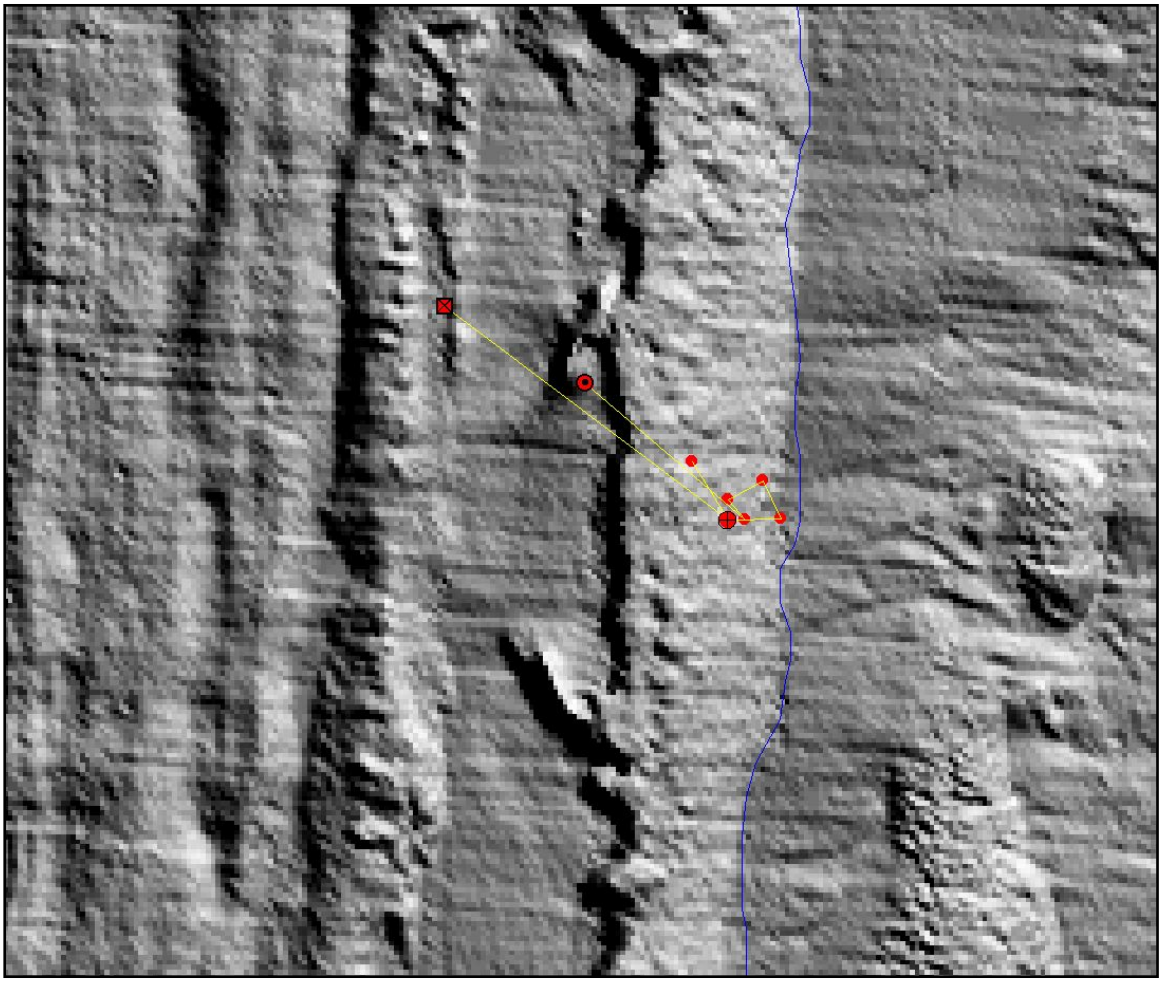


Figure B. **3-99-645: tracking locations**. Red closed circle –original capture site (03/15/99) and starting location (03/16/99), red cross-haired circle – tracking endpoint and red X-Square – recapture site (03/19/99). Blue line indicates the eastern edge of the 2nd reef crest.

#5. 3-00-357: The female stingray was captured at 0958h (03/02/00) while resting under a rocky overhang in water 8.5 m deep. The animal had multiple scars and bite marks that are consistent with injuries incurred during mating activities. Tracking commenced at 1233h the same day and was performed for 24.25 hours with the animal remaining liberated in order to conduct further work. A direct observation at 1125h on 03/03/00 revealed the animal fully buried (only tag exposed) and a smaller female resting on a small sand patch ~5m away. Stingray #5 traveled a total distance of 786.6 m during the 24h track with a net movement of 103 m from starting position to finish location. Attempts to relocate the animal on 03/06/00 were non-productive after 4 hours of searching along the previous location and in adjacent areas (**Figure C**). An outlier was removed from the analysis after a diver towing a kayak went directly through the study site just prior to a considerable move northwest followed by a large circle back to the previous vicinity. This specific move was likely due to diver disturbance, resulting in a modified behavior.

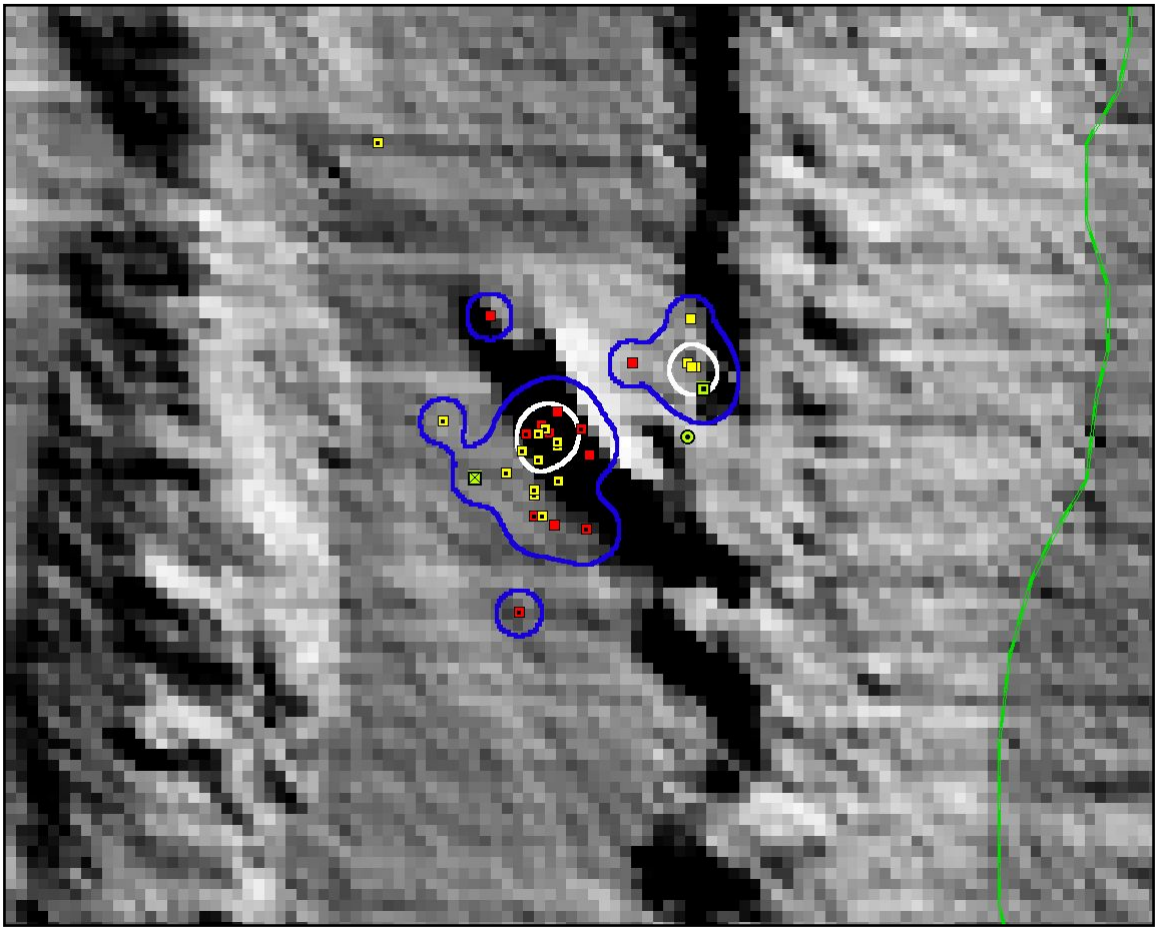


Figure C. **3-00-357: tracking locations**. Closed green circle represents the capture site, closed green square – start location, green X-square – track endpoint. Open yellow squares – Day 1, closed yellow squares – Day 2, open red squares – Night 1, closed red squares – Night 2. The blue contour represents the total (24h) 95% KUD and the white contours are the partitioned 50% core areas.

#6. 9-00-339, a female stingray was captured at 1002h (09/27/00) while resting on rocky substrate in water 9.5 m deep. Tracking commenced the same day at 1338h, however, early weather conditions prompted a delay of tracking and data collection for several hours (1550-2052h). The animal displayed reduced movements from 2100-0100 during the time when peak activity in most cases has been observed. Subsequent activities remained elevated in a circular pattern of movement until 0523 when receiver failure occurred and tracking was ceased. Stingray #6 traveled a total distance of 764.5 m during the 20-h track with only a net displacement of 37.1 m. The tag was recovered unattached to the animal on 10/05/00 in a large sandy area dominated by gorgonians ~108m east of the previous location. Numerous conspecifics (3 female and 1 male) were observed in the general area, suggesting stingray #6 might still have been in the surrounding vicinity. Unlike most observations, the 50% core area was dominated by concentrated nocturnal locations (**Figure D**).

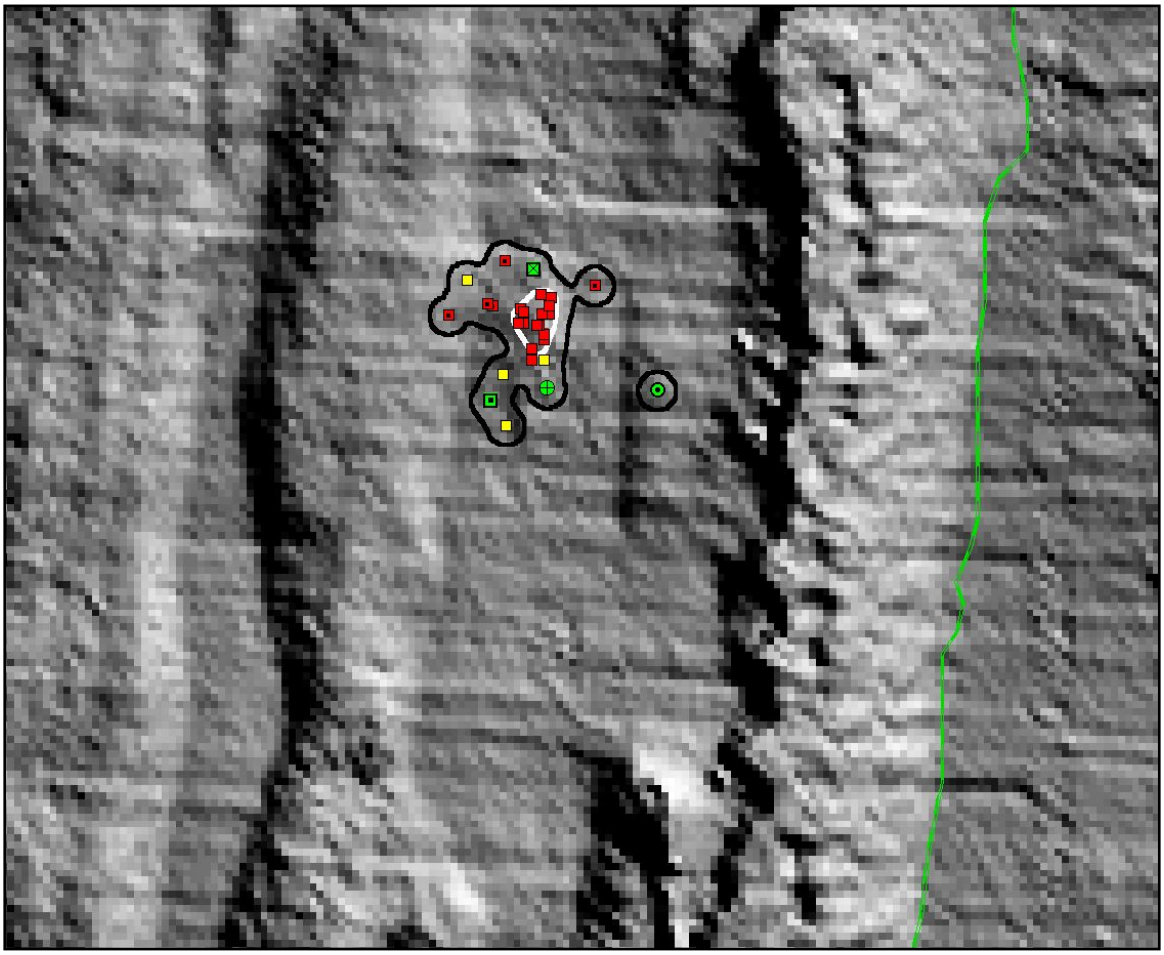


Figure D. **9-00-339: tracking locations**. Closed green circle – capture site, closed green square – start location, cross-haired green circle – endpoint location and the green X-square – reacquire tag site. Open yellow squares – Day locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total 95% KUD and the white contours are the 50% core areas for all locations combined. The green line indicates the eastern edge of the 2nd reef crest.

#7. 9-00-447, a gestating female stingray was captured at 0910 (09/27/00) while resting on rocky substrate in water 33 feet (10.1m) deep. Tracking commenced the same day at 1330h with the same weather delay as stingray #6. The animal showed consistent movements throughout much of the track moving first north and then south of the initial capture area. Stingray #7 demonstrated a more elongated pattern of movement along the eastern portion of the second reef. Peak activity occurred between 0130-0445 and the total distance traveled was 1151.5 m with a net displacement of 434.9 m to the south. Upon recapture at 1510h (10/05/00), stingray #7 had traveled back to the northern extent of the identified 95% activity space for a total distance of ~631 m from the previous location. Transmitter signal interference made achieving ground zero difficult and the animal was eventually recaptured under a rocky overhang with several conspecifics (2 female and 1 male) in the nearby area (**Figure E**).

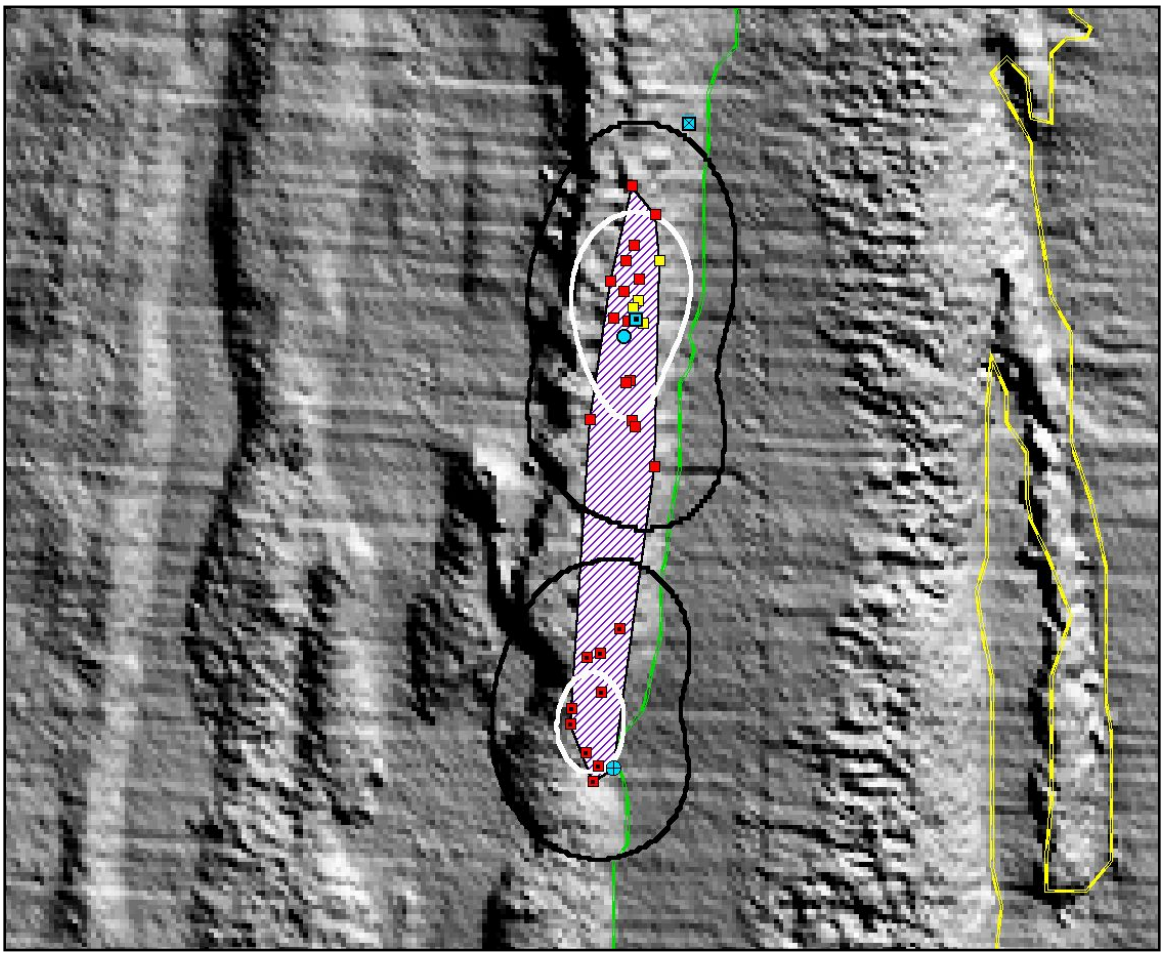


Figure E. **9-00-447: tracking locations**. Open blue circle – capture site, closed blue square – start location, blue cross-hair circle – endpoint location and blue cross-hair square – recapture site. Open yellow squares – Day locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total 95% KUD and the white contours are the 50% core areas. The green line indicates the eastern edge of the 2nd reef crest and the yellow line indicates the eastern edge of the 2nd reef terrace, blue hatched polygon represents the 95% MCP for all locations.

#8. 12-00-456, a male stingray was captured at 0914h (12/12/00) while resting on a sand patch in the middle of patchy hardbottom in water 10.7 m deep. Tracking commenced the same day at 1133h, but was interrupted twice due to weather conditions so continuous monitoring was divided intermittently across several days. The first session lasted 14.5h (1133 - 0158h) on 12/13/00 and the second session lasted 15.5h (0848-1520h) on 12/14/00. During active tracking, the movements appeared somewhat meandering within a confined area. Movements between tracking days evidenced larger displacements, yet stayed within a region along a narrow expanse of the eastern portion of the second reef crest. The ray shifted ~294 m north by 12/14/00 (0848h) where it continued to meander within a restricted area. Eventually stingray #8 was recaptured on 12/17/00 (1035h) further south than the original capture site ~385 m away from the end of the previous tracking session **(Figure F).**

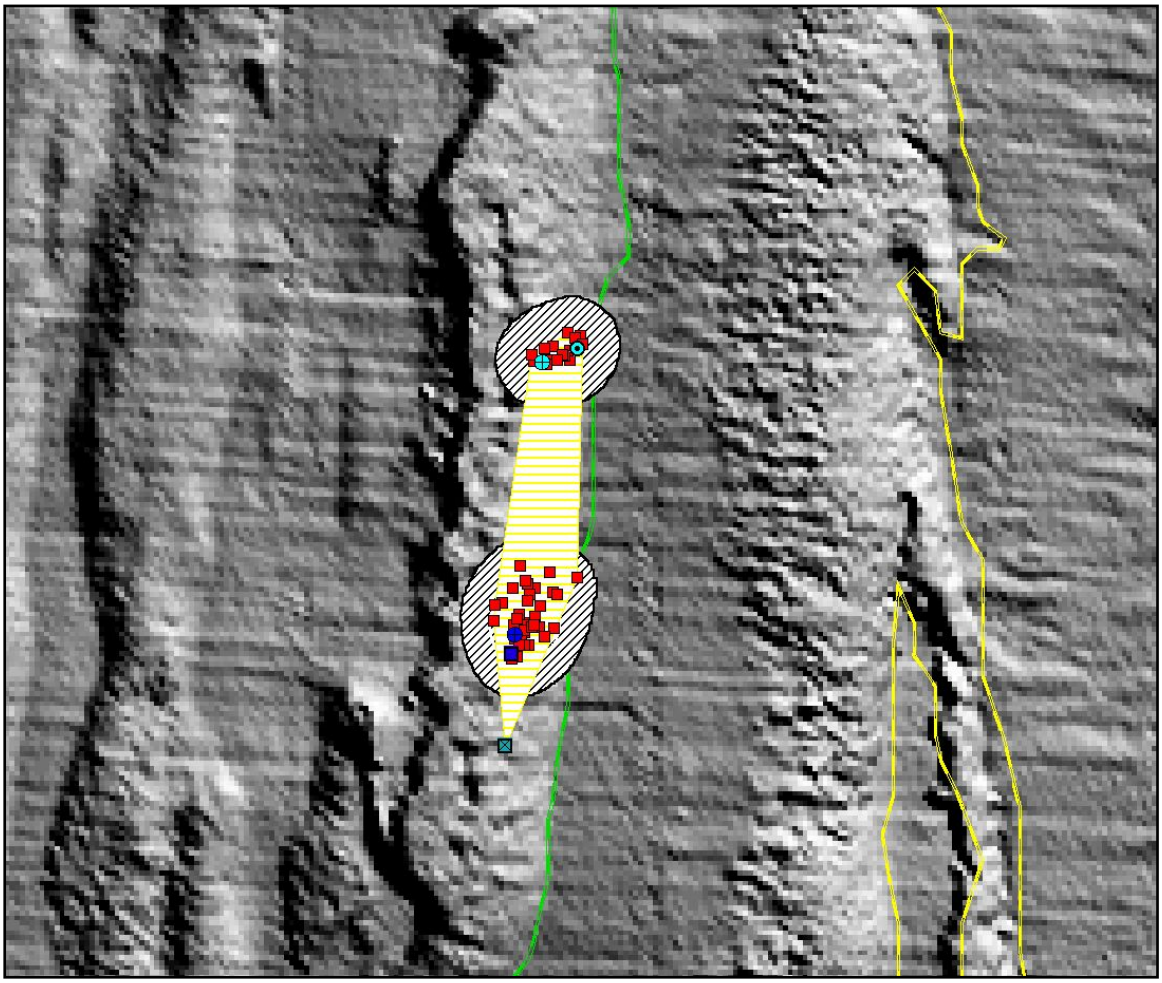


Figure F. **12-00-456: tracking locations**. Dark blue square – capture site and start location (12/12/00), cross-haired blue circle – end of tracking (12/13/00), lower red squares represent the total locations during the initial tracking session, light blue closed circle – start of 2nd day of tracking (12/14/00), cross-haired light blue circle is the endpoint location and higher positioned red squares are the corresponding locations. The medium blue X-square is the recapture site on 12/17/00. The yellow hatched polygon represents the MCP 95% activity space and the black hatched contours indicates the combined 95% KUD. The green line displays the eastern edge of the 2nd reef crest and the yellow line is the eastern edge of the overall 2nd reef terrace.

#9. 1-01-447, a gestating female stingray was captured at 0920 h (01/16/01) buried among the sand within patchy hardbottom in water 11 m deep. Tracking was initiated on the same day as capture with a two-hour delay for animal acclimation to transmitter and recovery from anesthesia. Stingray #9 was monitored continuously for 24h from 1158-1200h (1/16-1/17/01) and recaptured the following day at 0930h. Much of the initial confined movements were conducted at the original site of capture within the primary core area. Elevated activities initiated around sunset (1752h) with repeated moves out of and back into the primary core area. Larger moves were conducted by 2143h with an eventual southerly trend by 0144h. The ray traveled a total distance of 1504.3 m with only a minimal displacement of 51.3 m from start to finish. Stingray #9 was 38.5 m east of the previous location at the time of recapture (0920h) the following morning (01/18/01) buried along the sand/reef interface under a large solitary gorgonian (**Figure G**).

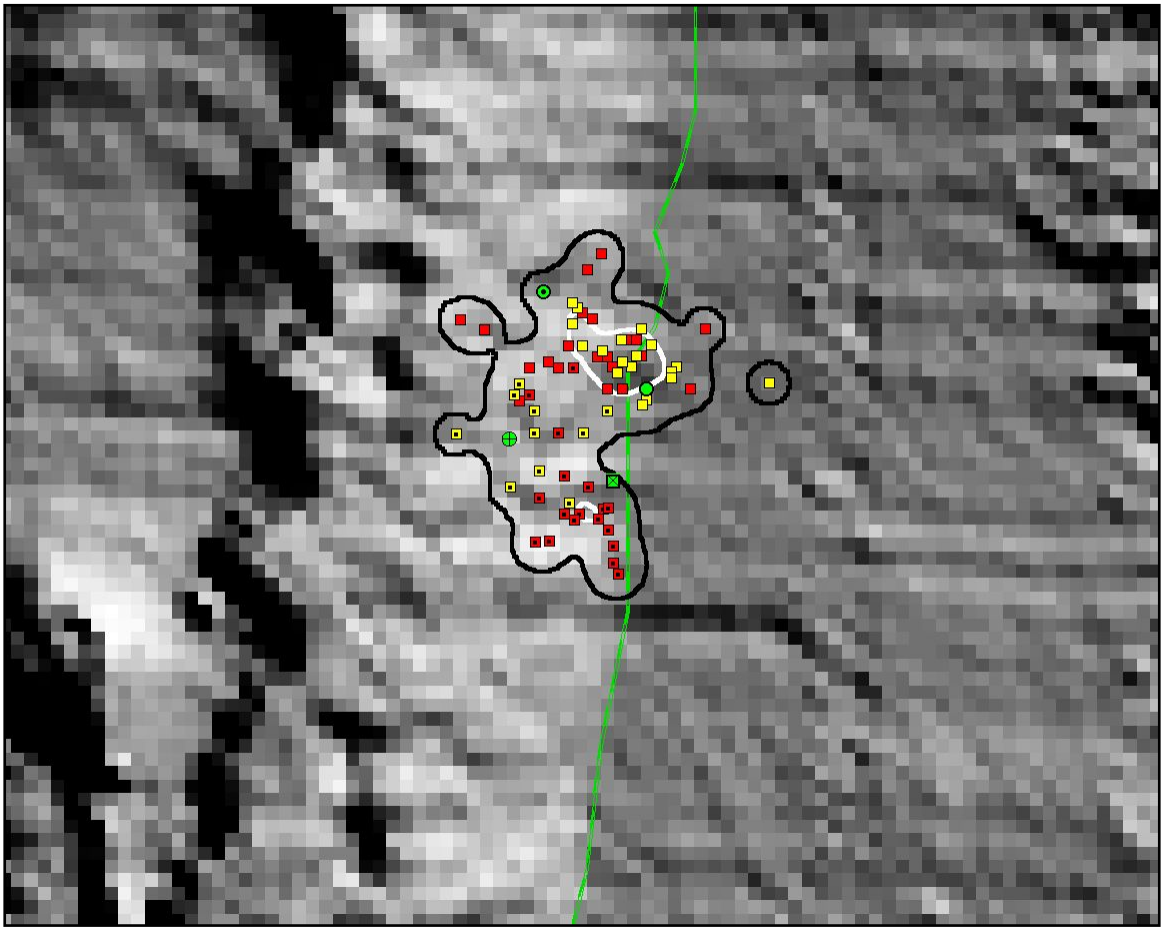


Figure G. **1-01-477: tracking locations**. Open green circle – capture site, closed green circle – start location, cross-haired green circle – endpoint location and the green X-square – recapture site. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. The green line indicates the eastern edge of the 2nd reef crest.

#10. 1-01-456, a gestating female stingray was captured at 0951h (01/16/01) partially buried among sand within the hardbottom community in water 11.3 m deep. Stingray #10 was tracked simultaneously with #9 and situated slightly to the north along an adjacent area of the second reef. The stingray was monitored continuously for 24h from 1205-1209h (1/16-1/17/01) and recaptured the following day at 1110h (01/18/01). The first move outside the elongated core area occurred by 1839h, followed by an increase in observed movelengths. By 2151h even larger moves had begun with a considerable move south along the reef edge, followed by a return north within the interior of the reef slope. Observed locations during the 2300-2400h interval were within 21 m of stingray #9 where a clear line partitioning each rays activity space was indicated (**Figure I**). Stingray #10 traveled a total distance of 1321.5 m yet exhibited only a small net displacement of 57.5 m. The animal was recaptured the following day at 1110h ~72 m south between the original capture site and the core area of tracking. The total distance from the capture site on 01/16/01 to the recapture site on 01/18/01 was ~31 m (**Figure H**).

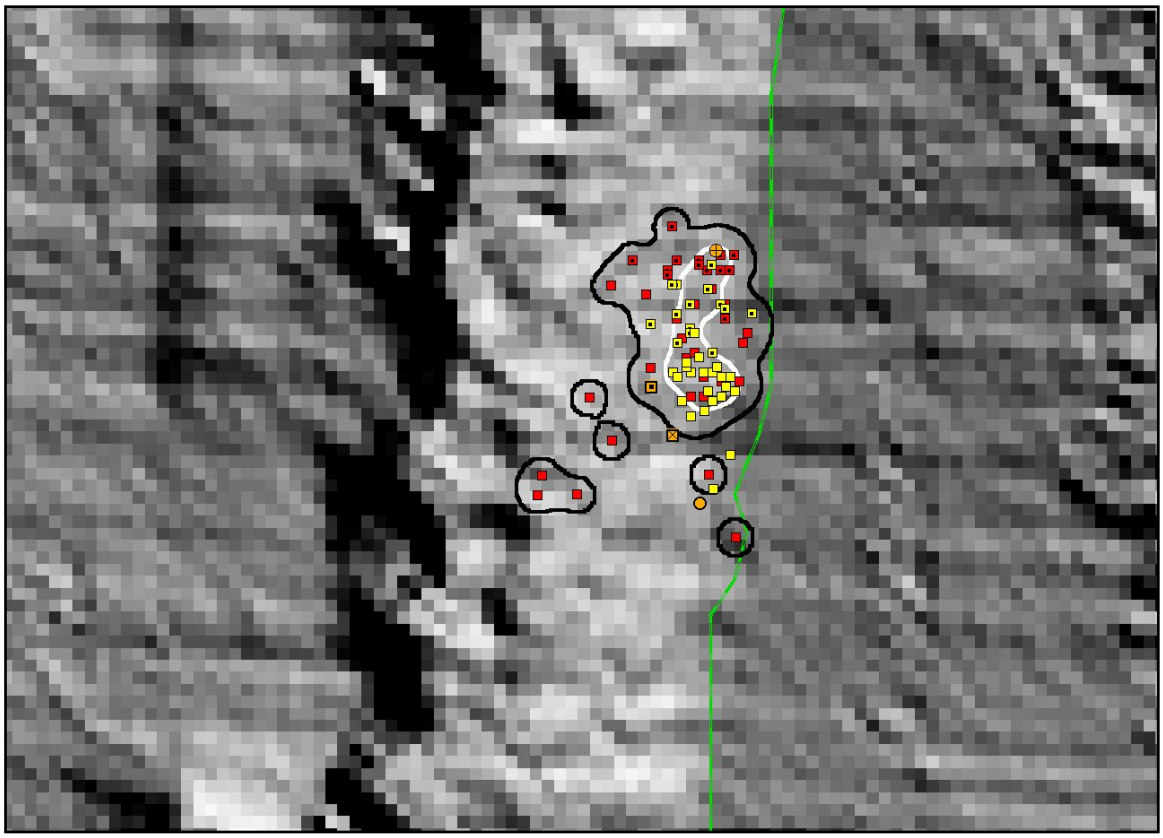


Figure H. **1-01-456: tracking locations**. Open orange circle – capture site, closed orange square – start location, cross-haired orange circle – endpoint location and the orange X-square – recapture site. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. The green line indicates the eastern edge of the 2nd reef crest.

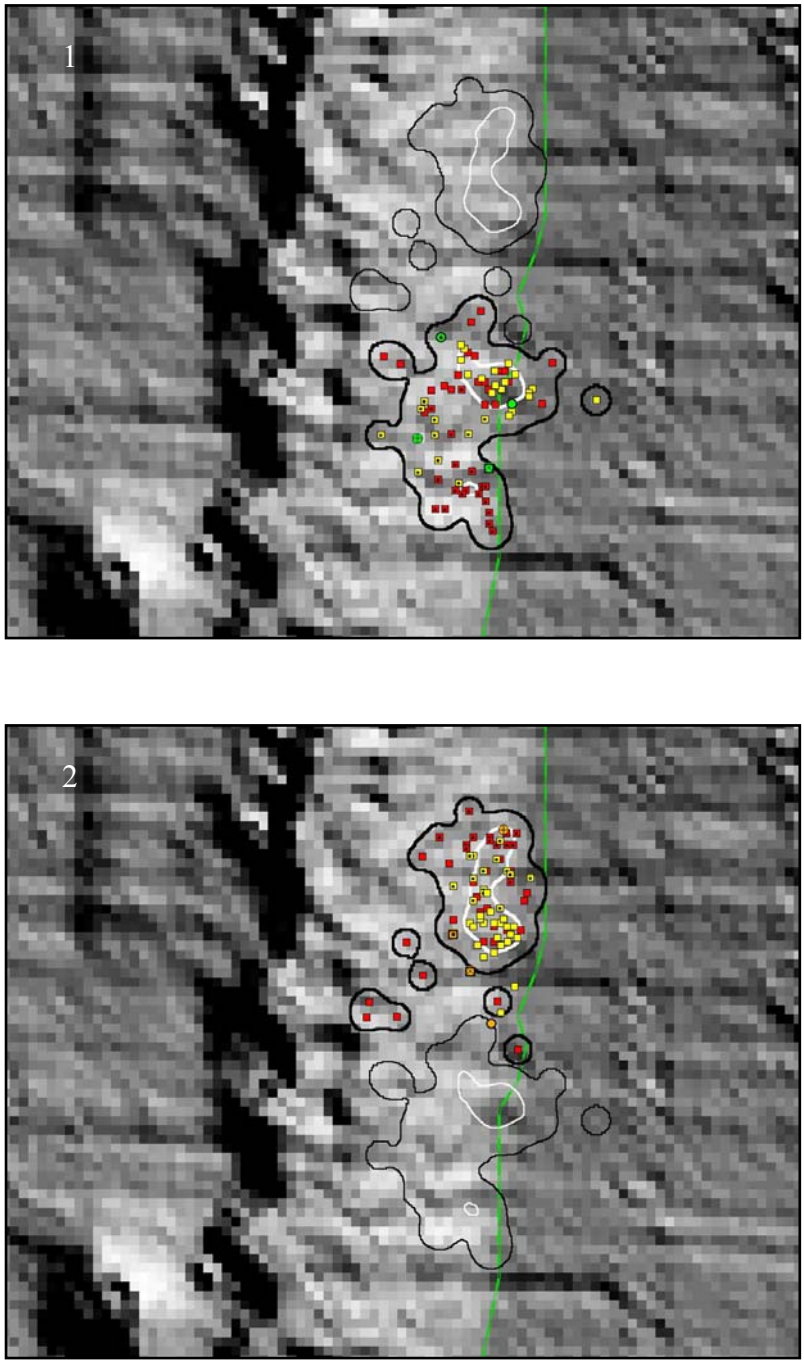


Figure I. Comparison of January 2001 KUD. **1**. 1-01-477 KUD with day (yellow) and night (red) locations and superimposed 1-10-456 KUD. **2**. 1-01-456 KUD with day and night locations and superimposed 1-01-447 KUD. Note how the 95% KUD of both animals are adjacent but never overlap, although the capture site for 1-01-477 is situated within the 95% KUD contour of 1-01-456.

#11. 4-01-339, a female stingray was captured at 0958h (04/16/01) while resting exposed on sandy substrate along the western edge of the first reef community in water 4.9 m deep. The animal was continuously tracked for 25.5h from 1028-1203 with a single three-hour weather delay (1600-1900h). Stingray #11 had several scars and bite marks indicating recent mating events and exhibited consistent movements at the onset of tracking. A late afternoon period of quiescence was interrupted by a severe thunderstorm and by 1908h active movements had recommenced. Tightly grouped meandering persisted until a northerly move occurred after 2400h. A second smaller core area was formed by 0528h, followed by consistent tallies back and forth between both core areas. Stingray #11 traveled a total distance of only 901.2 m with an equally low measure for net displacement of 37.3 m. The point-to-point distance from the capture location to the endpoint/recapture site was 79.7 m (**Figure J**).

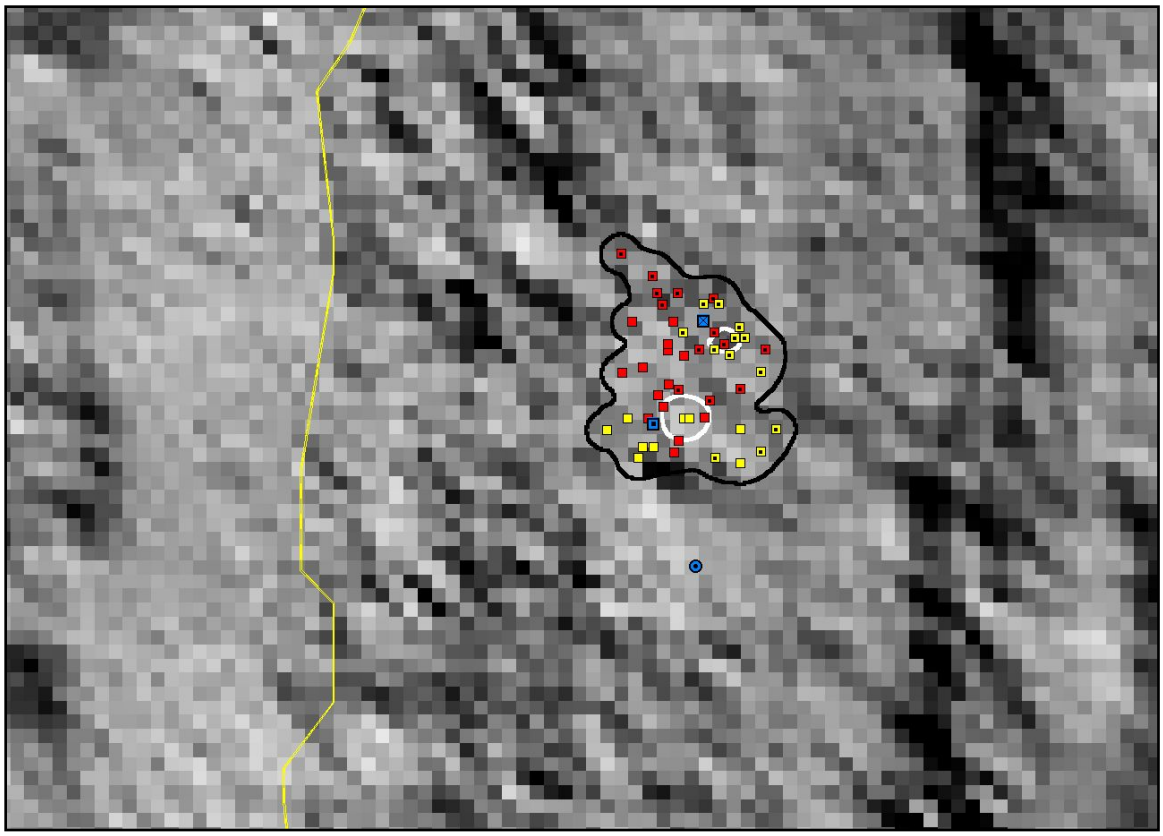


Figure J. **4-01-339: tracking locations**. Open blue circle – capture site, closed blue square start location and blue X-square is the endpoint and recapture site. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. The yellow line indicates the western edge of the 1st reef.

#12. 4-01-447, a female stingray was captured at 0900h (04/16/01) resting exposed on a sandy patch within the first reef hardbottom community in water 3.7 m deep. Stingray #12 was tracked simultaneously with #11 and initially displayed a somewhat confined meandering pattern of movement, remaining in the same area as stingray #11. By 1547h stingray #12 was observed at the latter rays core area with positions recorded only 7.1 m apart (indicating a possible social interaction). A long southerly shift occurred between 1909 – 2353h, where the ray eventually reached the location of its computed core area. There was consistent meandering until 0805h, when the stingray appeared to remain confined within a smaller region. Stingray #12 moved a considerable distance for a total of 1350.4 m and also demonstrated a larger net displacement of 203.5 m from start to finish in comparison to stingray #11. The point-to-point distance from capture to recapture was similar with a total of ~725 m (**Figure K**).

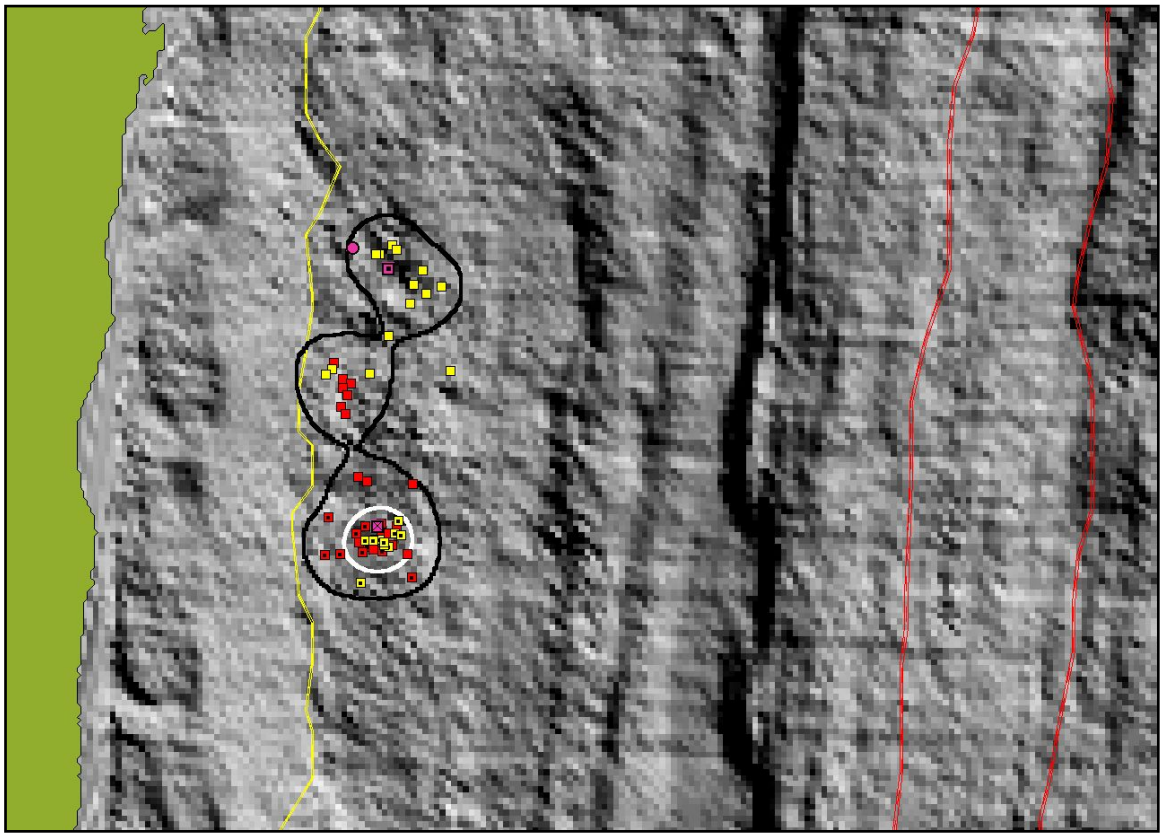


Figure K. **4-01-447: tracking locations**. Open pink circle – capture site, closed pink square start location and pink X-square is the endpoint and recapture site. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. The yellow line indicates the western edge of the 1st reef.

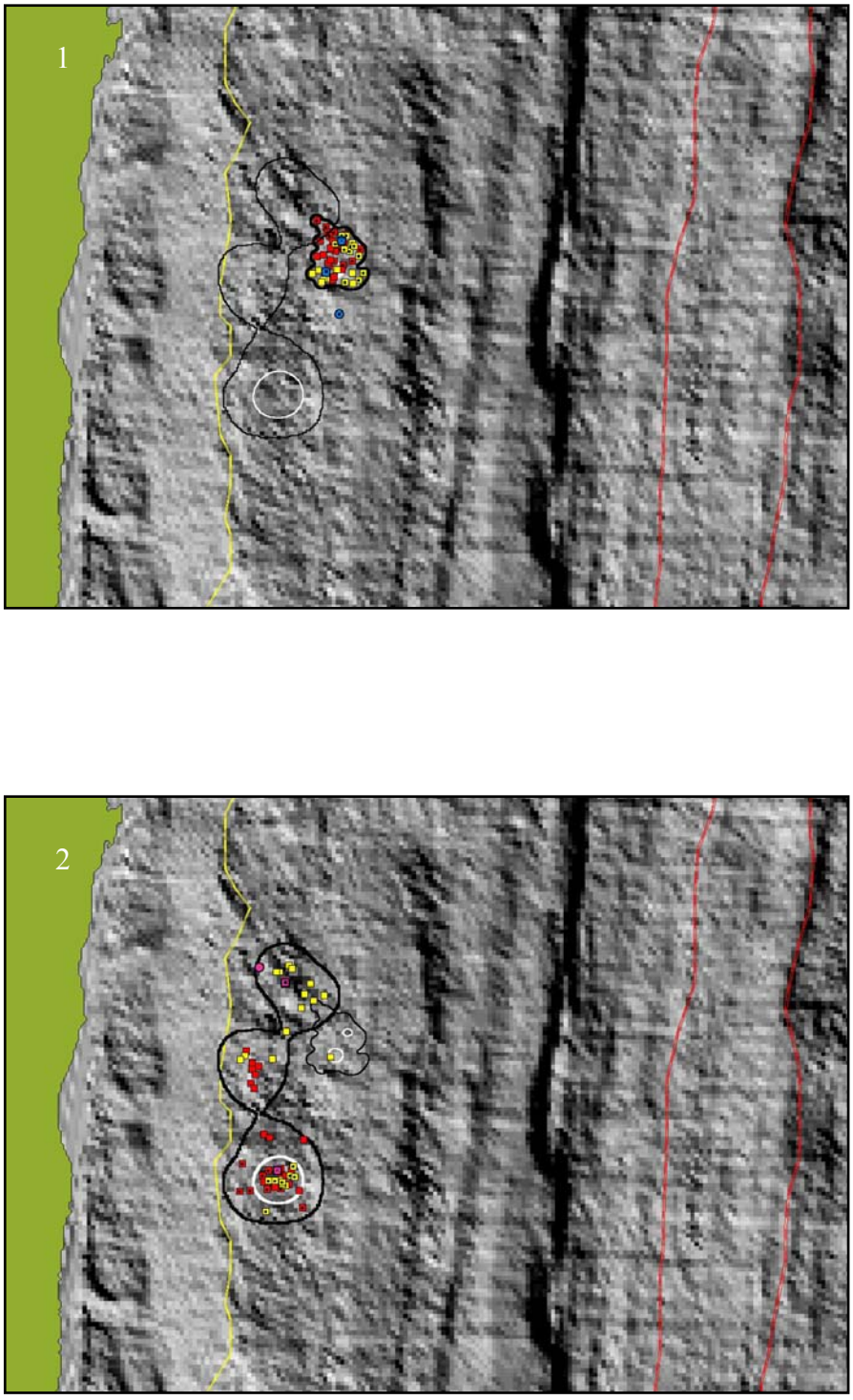


Figure L. Comparison of April 2001 KUD. **1**. 4-01-339 KUD with day (yellow) and night (red) locations and superimposed 4-10-447 KUD. **2**. 4-01-447 KUD with day and night locations and superimposed 4-01-339 KUD. Note slight overlap of 95% KUD of both animals and difference in KUD shape in relation to position within reef (interior – circular and boundary – elongated).

#13. 5-01-447, a gestating female stingray was captured at 1338h (05/22/01) resting uncovered on patchy hardbottom within the interior of the first reef in water 4.0 m deep. Tracking was initiated the following morning at 0920h and was continuous for 26h with two separate weather delays of 4.5h (1430-1900h) and 2h (0200-0400h) due to severe thunderstorms. The animal made small-scale movements in a meandering fashion during the morning hours and completed a larger move of 142 m NW at midday (1254h). Following the first weather delay, a significant move further north was made by 1829h with an even larger move SW (~247 m) by 1850h (possibly induced by decreased light conditions from storm). By 2332h the animal had reached the second larger core area, where movements persisted within a slightly confined area. The stingray made one final shift east at 0708h and remained motionless at the recapture site for one hour. Stingray #13 traveled the furthest combined distance of all tagged rays for a total of 1845.6 m, however, demonstrated a relatively low displacement of only 104 m. The total distance from capture site to the track start was extensive at nearly 274 m and was closely matched by the capture to recapture distance of ~247 m. The animal was recaptured at 1030h on 05/24/01 and later gave birth to three young in captivity during early June (**Figure M**).

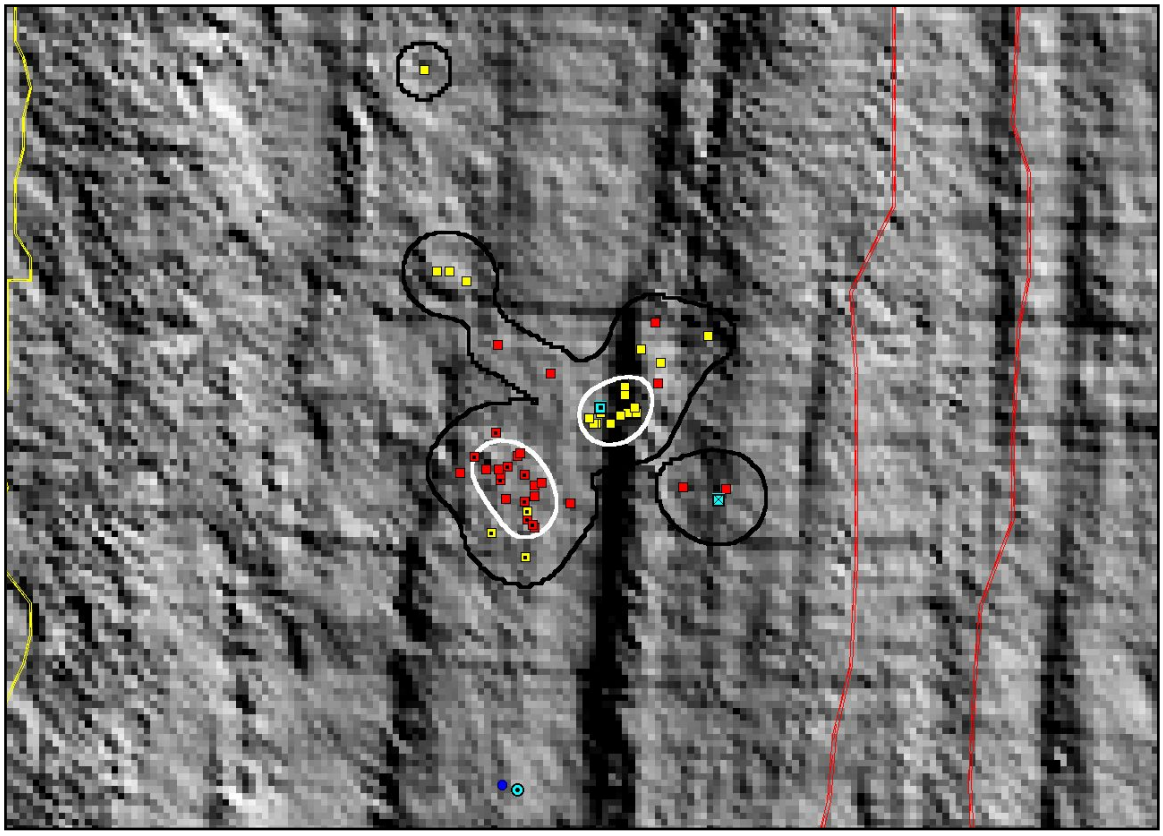


Figure M. **5-01-447: tracking locations**. Light blue closed circle – capture site (5/22/01), closed light blue square – start location (5/23/01) and the light blue X-square – endpoint and recapture location. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. The red lines indicate the transitional zone between the eastern edge of the 1st reef and the western edge of the 2nd reef. The open dark blue circle is the capture site for 5-01-456.

#14. 5-01-456, a gestating female stingray was captured at 1352h (05/22/01) mostly buried in sand along the same hardbottom region as #13 in water 4.0 m deep. Similar to stingray #13, stingray #14 shifted extensively to the north a total of 342.5 m by the onset of tracking the following morning (0840h). The animal immediately relocated south a short distance to the large-sized core area and made a number of small intermittent moves up to 1151h. After 1245h activity and movelength distances began to increase before tracking was interrupted by severe weather. Starting at 1842h significantly larger movelengths was observed with a swim path around and periodically through the entire core area. Stingray #14 activity remained slightly elevated on and off throughout the early morning, consistent in behavior with the simultaneously tracked stingray #13. Cessation of movements was evidenced by 1010h where the animal was recaptured in the same location 20 min later. Stingray #14 moved a total distance of 1215.9 m and had a small net displacement of 36.5 m. The total distance from capture to recapture consisted of 310.3 m all within the interior of the first reef (**Figure N**).

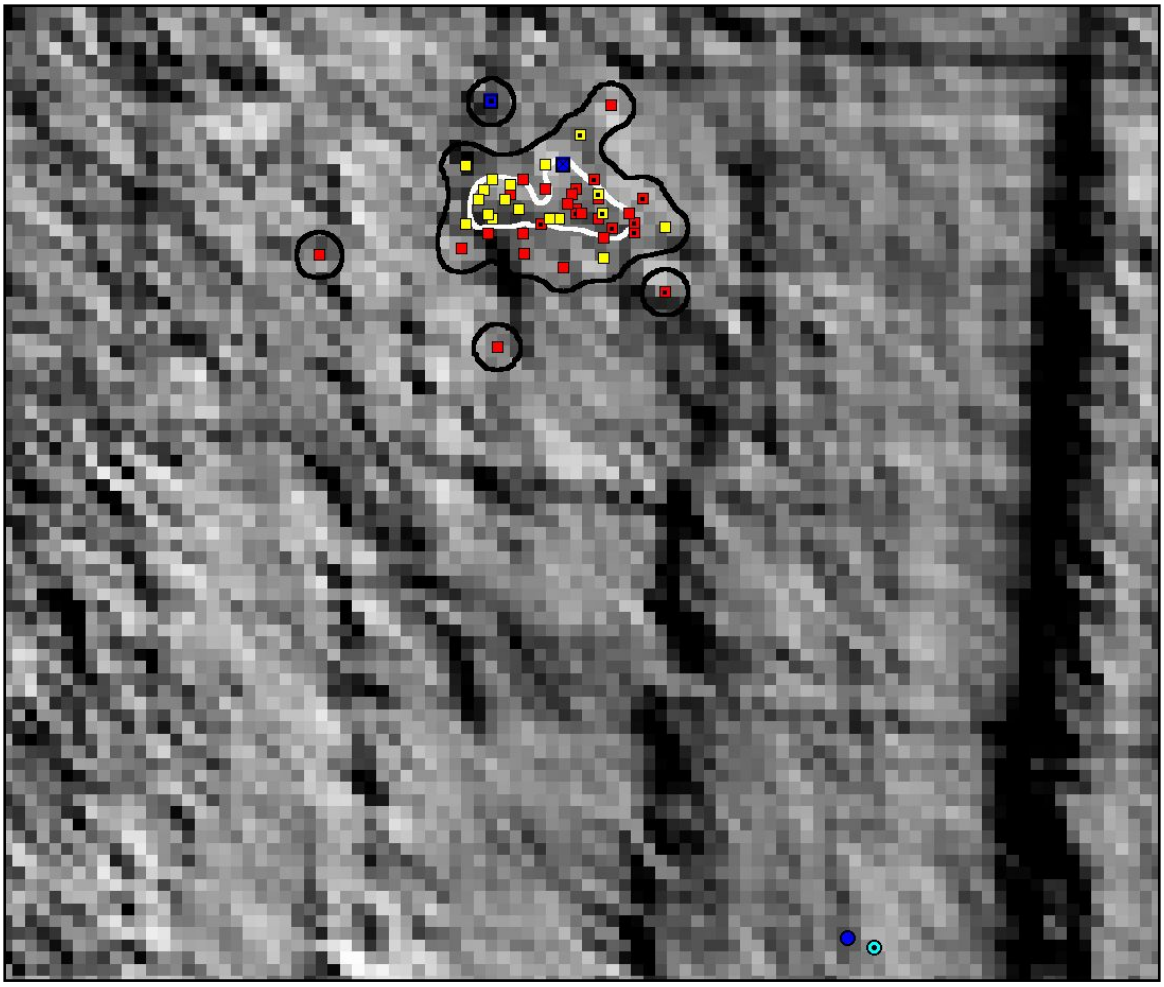


Figure N. **5-01-456: tracking locations**. Light blue closed circle – capture site (5/22/01), closed blue square – start location (5/23/01) and the blue X-square – endpoint and recapture location. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. The black contours represent the total (24h) 95% KUD and the white contours are the 50% core areas. Open dark blue circle is capture site for 5-01-447.

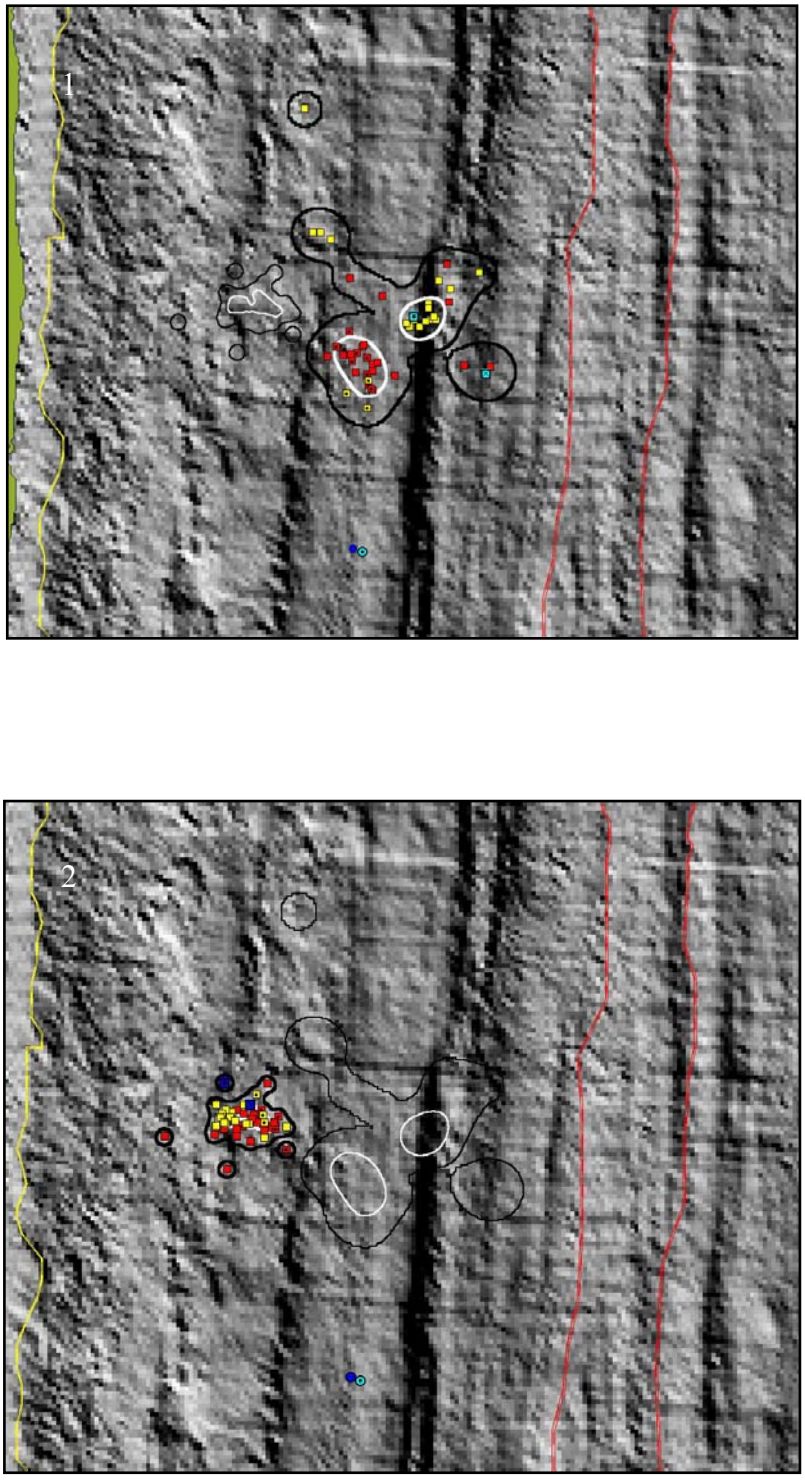


Figure O. Comparison of May 2001 KUD. **1**. 5-01-447 KUD with day (yellow) and night (red) locations and superimposed 5-10-456 KUD. **2**. 5-01-456 KUD with day and night locations and superimposed 5-01-447 KUD. Note how the 95% KUD of both animals are adjacent but never overlap and both animals made substantial moves north from the previous day capture sites.

#15. 8-01-339, a male stingray was captured at 0926h (08/23/01) while resting on consistent hardbottom in water 4.9 m deep. Little movement was evidenced before receiver failure (1515h) prevented any further tracking and the animal was recaptured within close proximity to the original capture site. Tracking was only accomplished for 4.25h (1102-1515h) (**Figure P**).

#16. 8-01-456, a female stingray was captured at 0846h (08/23/01) while resting on algal covered sandy bottom in water 4.9 m deep. Similar to stingray #15 very little movement was evidenced before receiver failure (1515h) and the animal was also recaptured in the vicinity of the original capture site with a slight move east to a small ledge. However, a single direct observation at 1145h exposed a second larger female resting next to the partially buried tagged stingray (8-01-456) (**Figure P**).

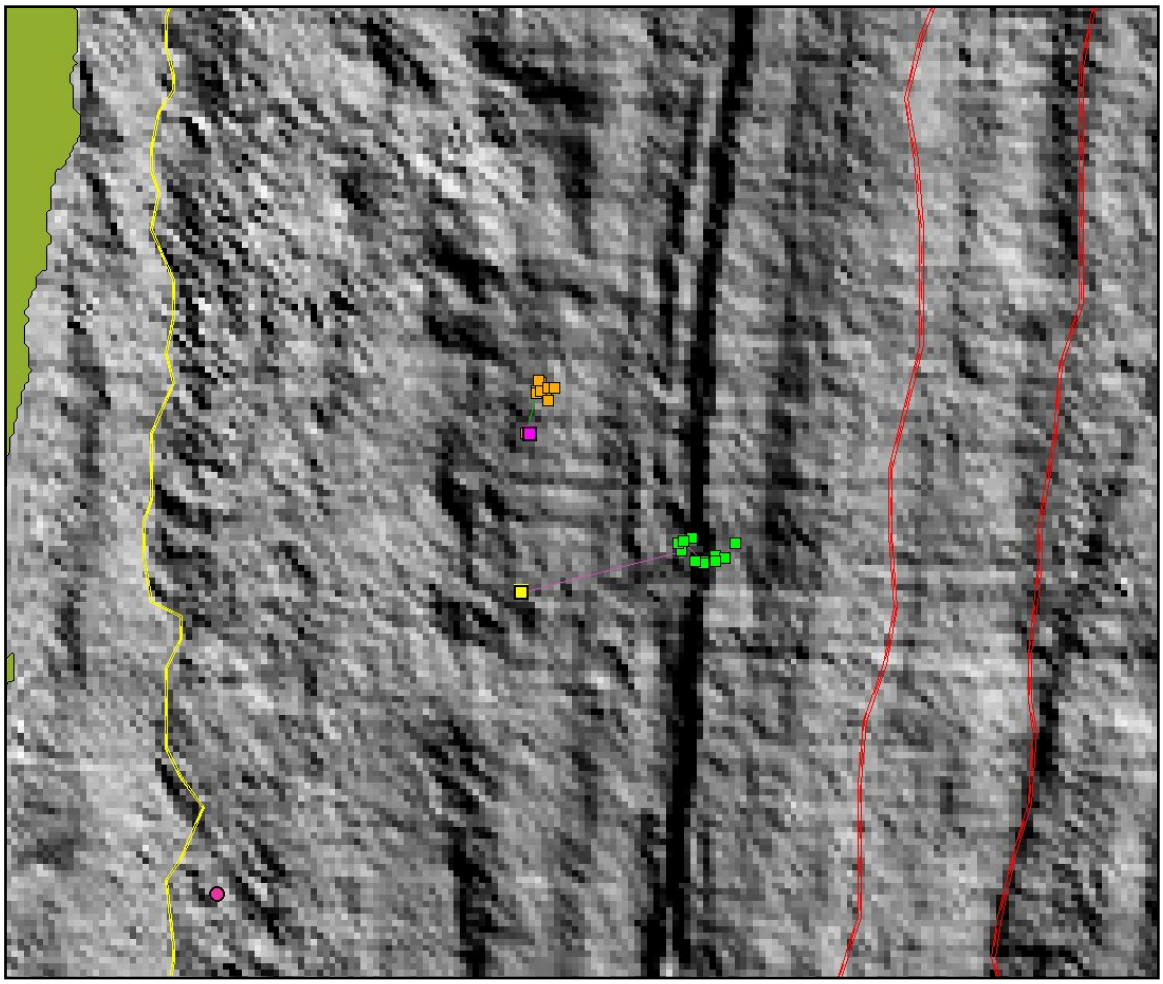


Figure P. **August 2001** capture locations and movements. Yellow square – 8-01-339 (capture site), green squares – **8-01-339** locations, pink square – **8-01-456** (capture site) and orange squares – 8-01-456 locations. Yellow line indicates the western edge of the 1st reef and red lines the transitional zone between the eastern edge of the 1st reef and the western edge of the 2nd reef.

#17. 9-01-456, a male stingray, was captured at 1435h (09/25/01) while resting uncovered over patchy hardbottom in water 4.3 m deep. Tracking was initiated the following morning (09/26/01) at 0811, at this time the animal was located 137.5m north of the capture site. There were several small-scale movements during the early morning, but the ray remained motionless for several hours before moving ~64m south at 1430. After the first move occurred, the presence of a smaller male was noted in the precise location just vacated by stingray 9-01-456. Additional small movements along the prominent interior ledge of the first reef continued and the ray was eventually relocated in the vicinity of the original capture site from the previous day. Larger meandering movements were initiated at 2002 when the animal moved west off the ledge to slightly deeper water by 2101. A northerly move along the ledge contour was begun at 2302 and continued north and eventually back onto the crest near the starting position by 2446. An extensive move of 624.5m to the east was conducted at 0145, crossing over the sandy rubble zone to the western edge of the second reef by 0216. Stingray #17 continued east up into the more consistent interior of the second reef community until altering the course of travel south by 0316. By 0458 the animal was located within the second core area adjacent to a small ledge. Little to no movement characterized the remaining portion of the tracking session until recapture at 1149. Stingray #17 traveled a total distance of 1572.6m from start to finish with an extensive displacement of over 409m. The total point-to-point distance from initial capture site to the end of track/recapture site was ~403m (**Figure Q**).

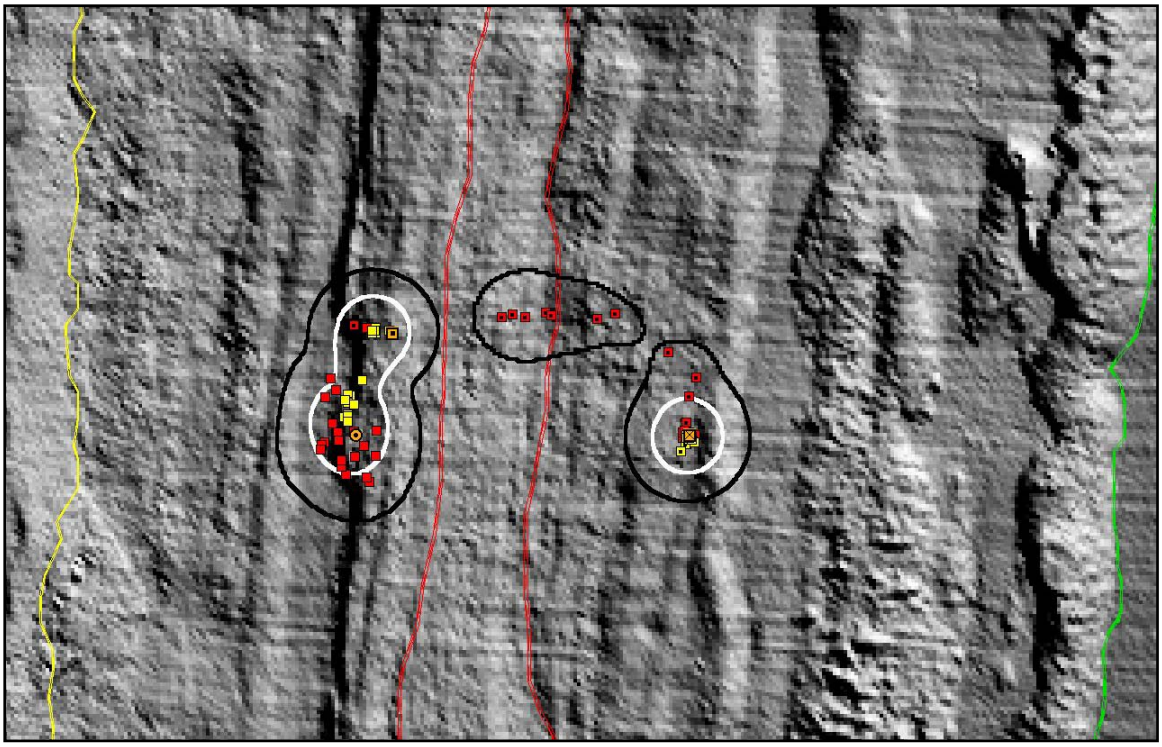


Figure Q. **9-01-456: tracking locations**. Closed orange circle – capture site (09/25/01), closed orange square – start location (09/26/01), orange X-square – endpoint and recapture site. Open yellow squares – Day 1 locations, closed yellow squares – Day 2 locations, open red squares – Night 1 locations and closed red squares – Night 2 locations. Black contours total (24h) 95% KUD and white contours 50% core areas. Yellow line – western edge of 1st reef, red lines – transition zone, green line – eastern edge of 2nd reef crest.

Appendix F. Individual Rate of Movement (ROM) Charts for (8) stingrays tracked for a full diel cycle.

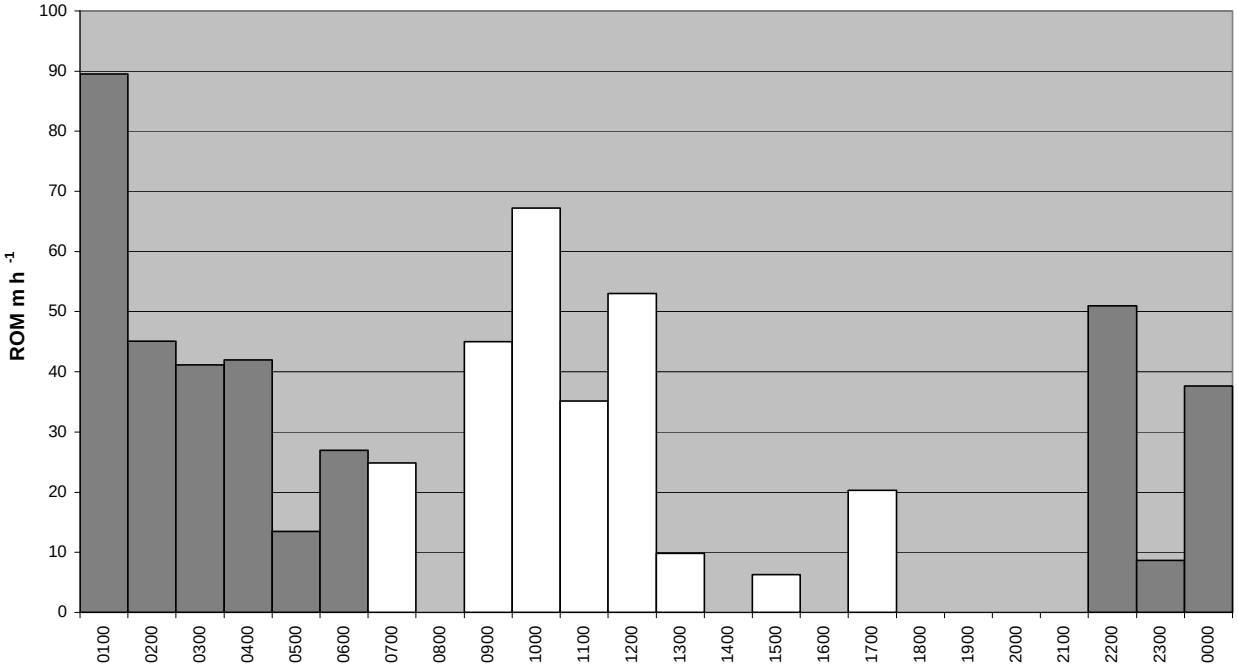


Chart 1. ROM for stingray #5 (**3-00-357**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

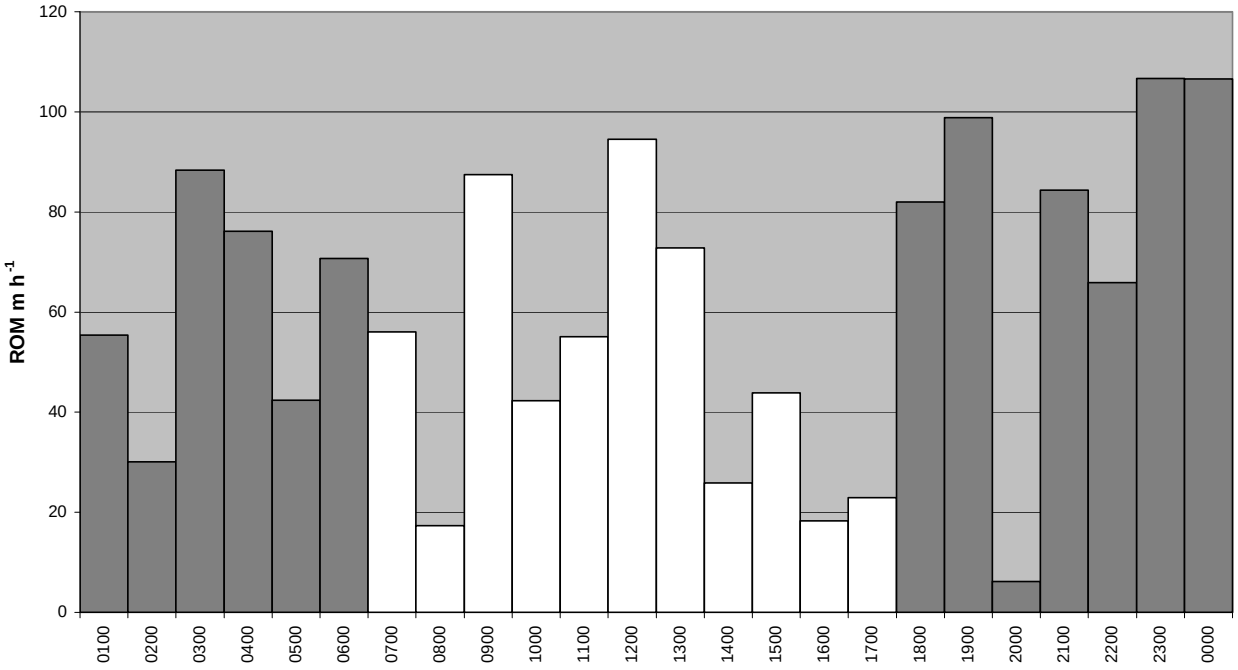


Chart 2. ROM for stingray #9 (**1-01-447**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

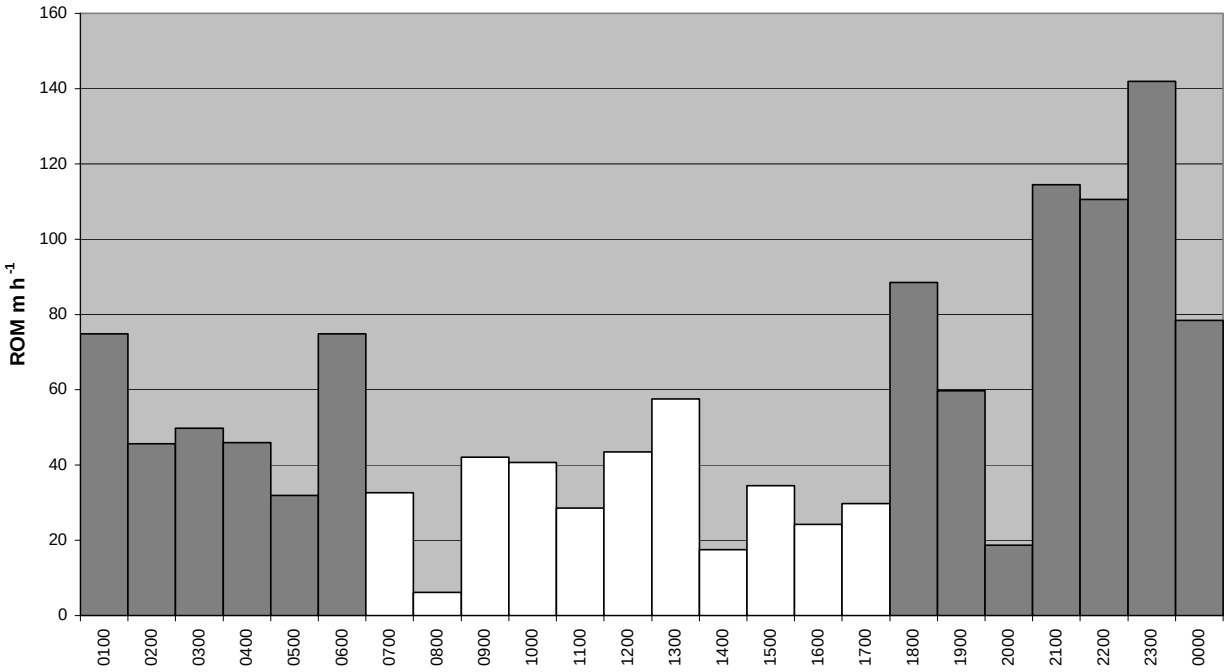


Chart 3. ROM for stingray #10 (**1-01-456**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

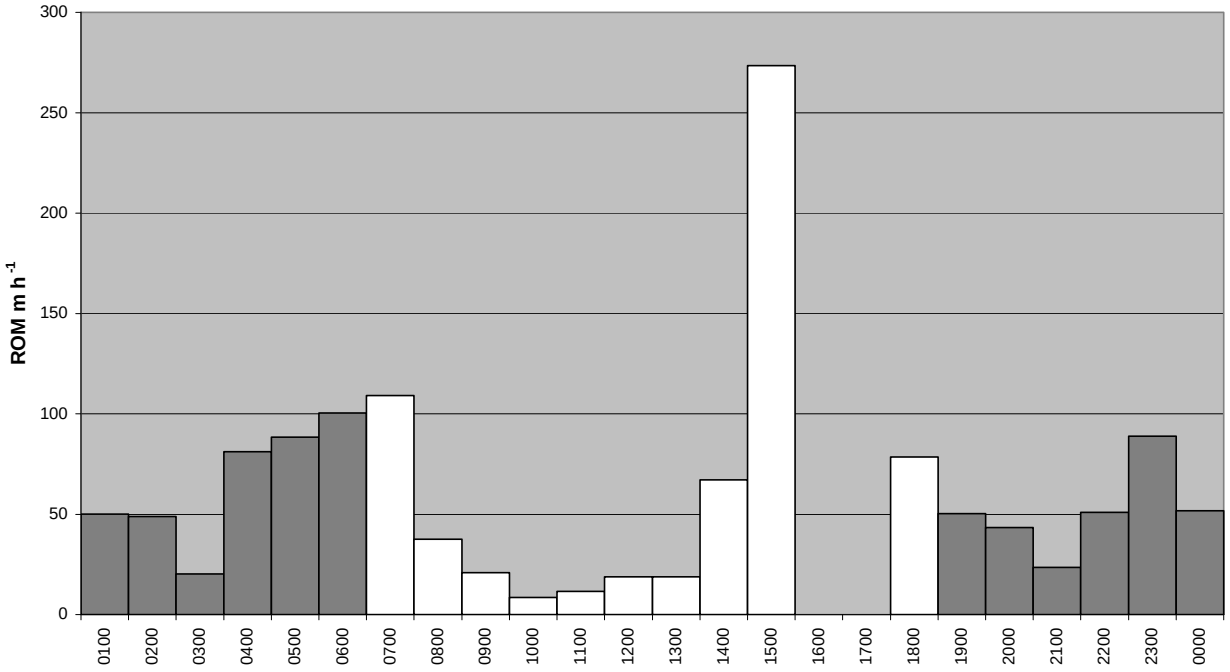


Chart 4. ROM for stingray #11 (**4-01-447**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

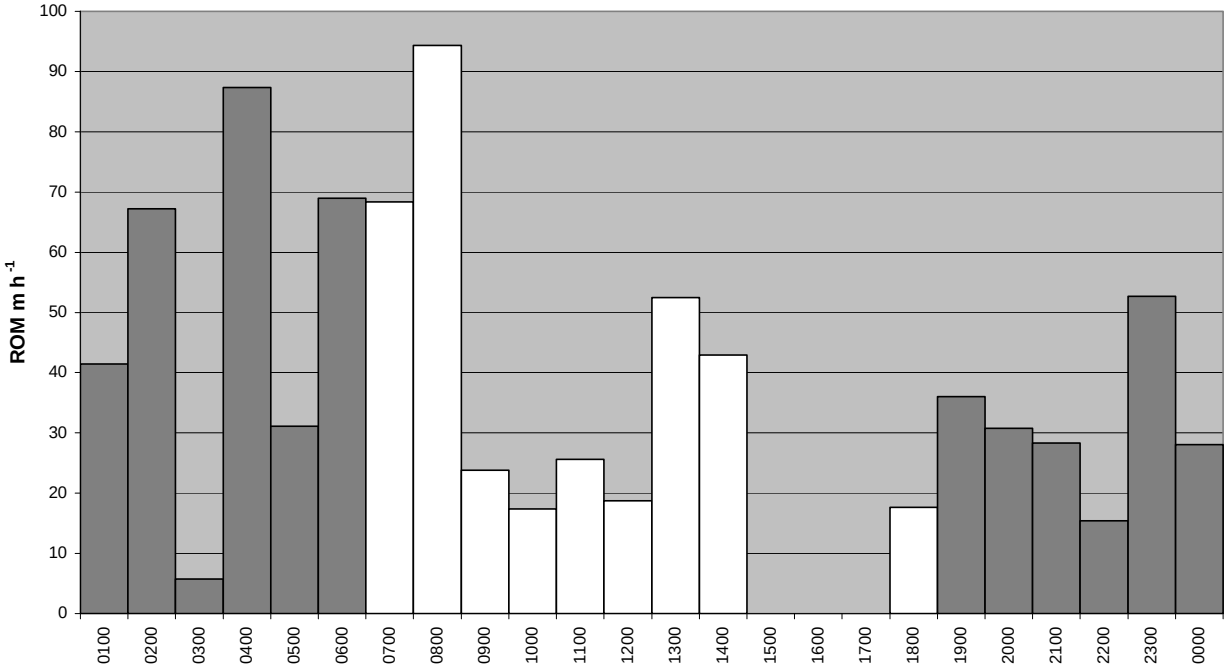


Chart 5. ROM for stingray #12 (**4-01-339**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

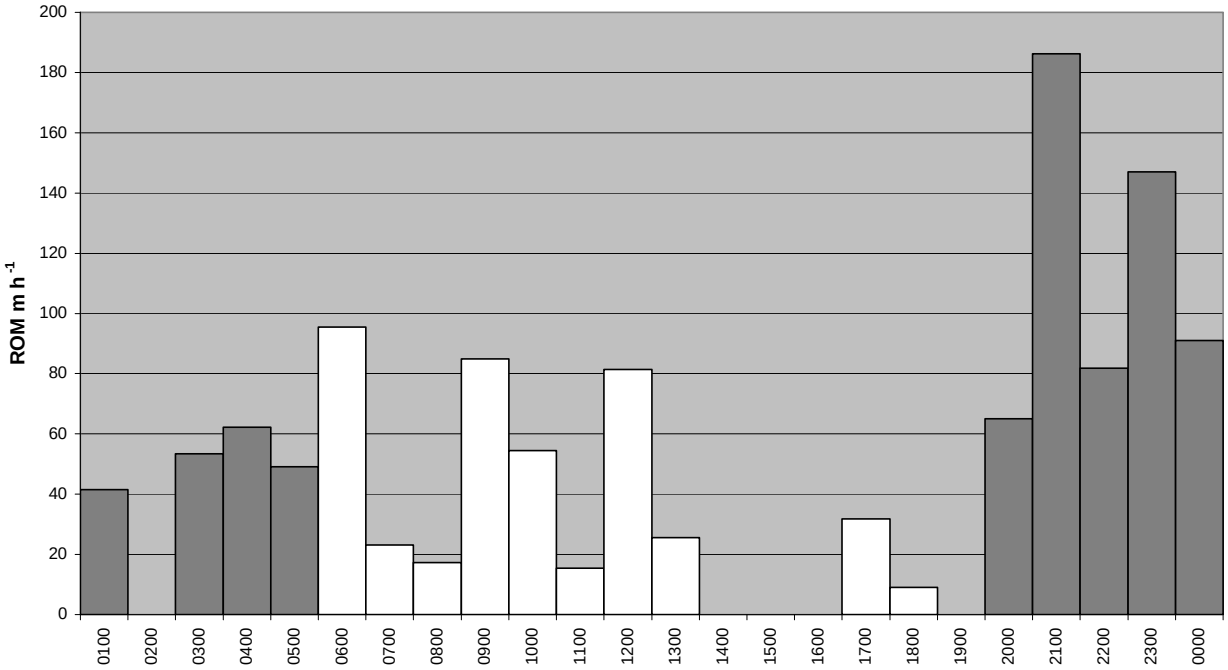


Chart 6. ROM for stingray #13 (**5-01-456**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

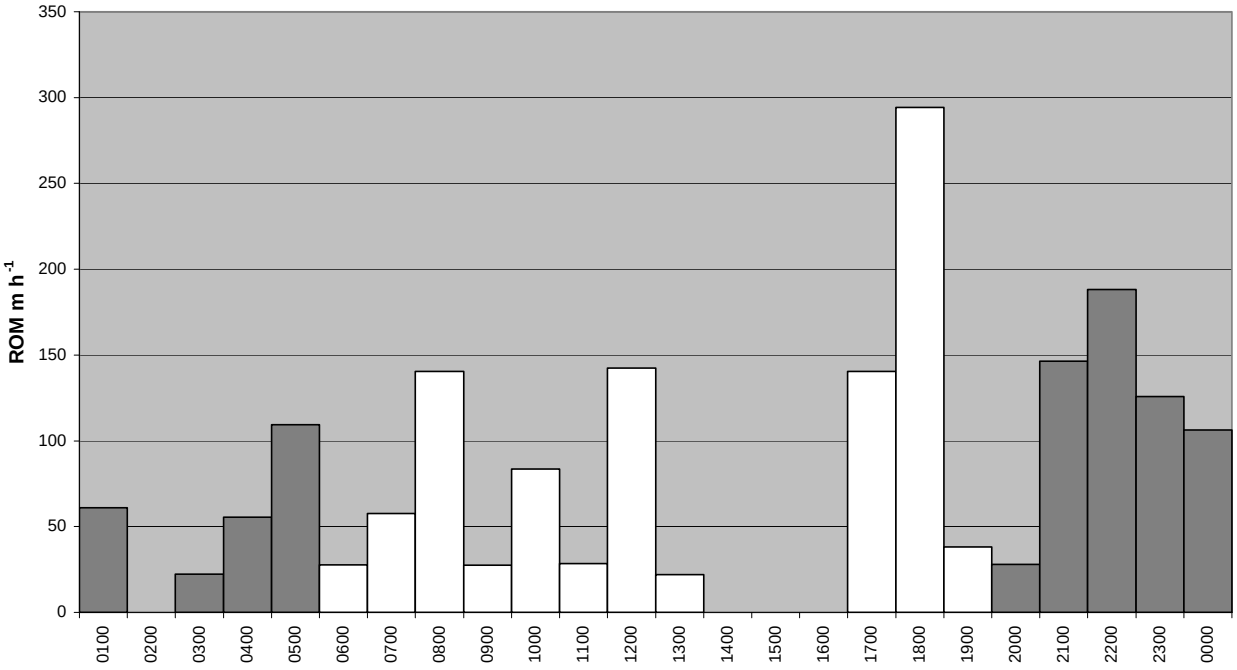


Chart 7. ROM for stingray #14 (**5-01-447**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

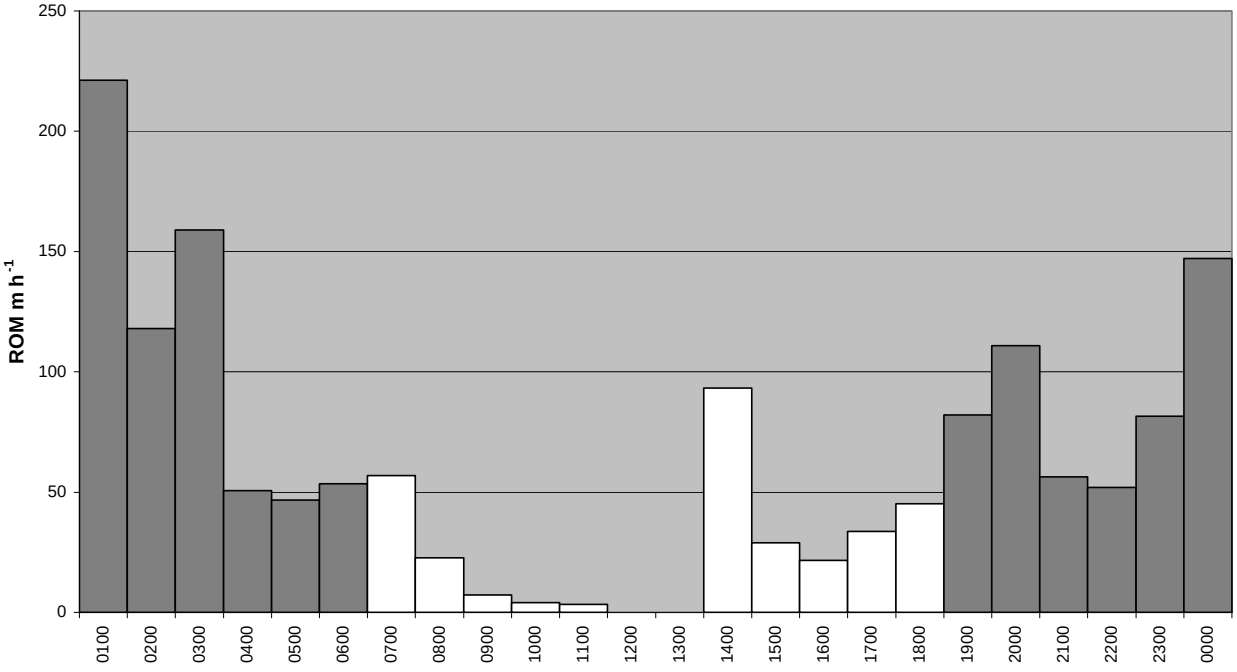


Chart 8. ROM for stingray #17 (**9-01-456**). Light bars represent diurnal movements and dark bars represent nocturnal movements.

Appendix G. Linearity Index values for 6-h divided data (Day 1, Day 2, Night 1 and Night 2), continuous nocturnal data (Total night) and for the entire 24h track (Total 24h), as well as, end-point (linear distance from initial to last location) and total distance (total accumulated distance traveled) in (m) for 24h linearity calculations.

Linearity	**3-00-357**	**1-01-456**	**1-01-447**	**4-01-339**	**4-01-447**	**5-01-447**	**5-01-456**	**9-01-456**
Day 1	0.51831	0.19228	0.10931	0.23272	0.20771	0.04581	0.07016	0.63067
Day 2	0.05602	0.11242	0.06345	0.07953	0.18669	0.18168	0.80693	0.08925
Night 1	0.19353	0.04461	0.07448	0.52863	0.24610	0.08098	0.17665	0.33371
Night 2	0.31438	0.06384	0.04960	0.09502	0.15336	0.13059	0.33774	0.43709
Total night	0.01974	0.05183	0.02853	0.03834	0.20771	0.15830	0.08590	0.37112
Total 24h	0.13163	0.03714	0.03221	0.04103	0.16539	0.05523	0.01754	0.25616
End-point Distance	103.2	57.5	51.3	37.3	203.5	104	36.5	409.1
Total Distance	786.6	1321.5	1504.3	901.2	1350.4	1845.6	1215.9	1572.6

Appendix H. Site Fixity Test Results: the gray highlighted values (*) indicate that the observed movements for both stingray **#11 (4-01-447)** and stingray **#17 (9-01-456)** were random with the latter animal exhibiting a slight degree of dispersal. All other stingray movements were confined. A *p*-value equivalent is provided for the significance level of simulated tracks (n = 1000) with mean squared distance (MSD) values greater than observed tracks. MSD is the measure of dispersion from the center of activity (mean location).

ID #	**RW > OBS**	***p* value**
3-00-357	97.2 %	0.028
1-01-456	99.9 %	0.001
1-01-447	99.9 %	0.001
4-01-339	99.9 %	0.001
4-01-447	44.1 %	**0.559***
5-01-447	99.3 %	0.007
5-01-456	99.9 %	0.001
9-01-456	5.8 %	**0.942***

Appendix I.

Table A. Kruskal-Wallis test results for the seasonal occurrence of *U. jamaicensis* in point counts from several combined studies in Broward County (all reefs combined). Refer to section (3.3) for details.

	n	***H* Statistic**	***p*-value**
Spring	296	4.02	0.134
Summer	298	4.01	0.134
Autumn	230	1.17	0.557
Winter	116	2.84	0.241

Table B. Kruskal-Wallis test results for the seasonal occurrence of *U. jamaicensis* in point counts from several combined studies in Broward County (by reef tract).

	n	**mean**	**SEM**	***H* Statistic**	***p*-value**
1st Reef					
Spring	81	0.148	0.140	-	-
Summer	172	0.128	0.030	-	-
Autumn	77	0.104	0.035	-	-
Winter	40	0.100	0.480	-	-
Total	370			1.14	0.768
2nd Reef					
Spring	103	0.107	0.036	-	-
Summer	63	0.222	0.057	-	-
Autumn	86	0.116	0.042	-	-
Winter	40	0.225	0.076	-	-
Total	292			7.28	0.064
3rd Reef					
Spring	112	0.063	0.023	-	-
Summer	63	0.159	0.046	-	-
Autumn	67	0.149	0.044	-	-
Winter	36	0.083	0.042	-	-
Total	278			5.49	0.140

Appendix I. (continued)

Table C. Kruskal-Wallis test results for the monthly occurrence of *U. jamaicensis* in point counts from several combined studies in Broward County (all reef tracts combined).

	n	***H* Statistic**	***p*-value**
A. January	69	2.67	0.263
February	39	1.52	0.468
March	49	0.588	0.745
April	89	3.54	0.170
May	158	3.26	0.196
June	147	3.95	0.139
July	52	5.87	0.053*
August	99	0.232	0.890
September	106	0.669	0.716
October	92	0.418	0.812
November	32	3.31	0.910
December	8	0.00	1.00

Table D. Kruskal-Wallis test results for the monthly occurrence of *U. jamaicensis* in point counts from several combined studies in Broward County (by reef tract all months combined).

	n	***H* Statistic**	***p*-value**
1st Reef	370	6.55	0.834
2nd Reef	292	12.59	0.321
3rd Reef	278	19.98	0.046*

Appendix J. Pairwise comparison (Mann-Whitney *U*-test) for all possible combinations between months for the occurrence of *U. jamaicensis* on the 3rd reef. Red numbers indicate a significant difference between means, suggesting the major difference from the original Kruskal-Wallis test was associated with November observations (Appendix I, Table D). Comparison between the months of May and June also displayed a significant difference.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-	0.372	0.764	0.925	0.173	0.195	0.485	0.495	0.865	1.000	0.024	1.000
Feb	0.372	-	0.463	0.387	0.624	0.150	0.554	0.244	0.338	0.372	0.040	1.000
Mar	0.764	0.463	-	0.807	0.485	0.215	0.755	0.426	0.667	0.764	0.041	1.000
Apr	0.925	0.387	0.807	-	0.178	0.128	0.512	0.400	0.774	1.000	0.012	1.000
May	0.173	0.624	0.485	0.178	-	0.004	0.746	0.097	0.106	0.173	0.000	1.000
Jun	0.195	0.150	0.215	0.128	0.004	-	0.080	0.546	0.231	0.195	0.254	1.000
Jul	0.485	0.554	0.755	0.512	0.746	0.080	-	0.212	0.395	0.485	0.009	1.000
Aug	0.495	0.244	0.426	0.400	0.097	0.546	0.212	-	0.583	0.495	0.102	1.000
Sep	0.865	0.338	0.667	0.774	0.106	0.231	0.395	0.583	-	0.865	0.028	1.000
Oct	1.000	0.372	0.764	1.000	0.173	0.195	0.485	0.495	0.865	-	0.024	1.000
Nov	0.024	0.040	0.041	0.012	0.000	0.254	0.009	0.102	0.028	0.024	-	1.000
Dec	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-

Appendix K-1. Monthly results for expected vs. observed frequencies of *U. jamaicensis* sex ratio on three reefs in Broward County. *G*-test conducted for all months with sample size $n > 25$ and binomial probability test for all samples sizes $n < 25$.

1st Reef

F:M	MONTH	*G* Stat Williams	*p*	Binomial *p*
4:3	JANUARY	n/a	n/a	1
15:8	FEBRUARY	n/a	n/a	0.210
2:1	MARCH	n/a	n/a	1
9:4	APRIL	n/a	n/a	0.267
9:3	MAY	n/a	n/a	0.159
16:16	JUNE	0	1	n/a
19:10	JULY	2.792	0.095	n/a
25:20	AUGUST	0.551	0.458	n/a
10:8	SEPTEMBER	n/a	n/a	0.815
21:12	OCTOBER	2.449	0.118	n/a
2:2	NOVEMBER	n/a	n/a	1
3:4	DECEMBER	n/a	n/a	1

2nd Reef

F:M	MONTH	*G* Stat Williams	*p*	Binomial *p*
20:11	JANUARY	1.990	0.158	n/a
13:22	FEBRUARY	1.873	0.171	n/a
11:18	MARCH	1.678	0.195	n/a
5:5	APRIL	n/a	n/a	1
5:6	MAY	n/a	n/a	1
8:10	JUNE	n/a	n/a	0.815
9:8	JULY	n/a	n/a	1
4:8	AUGUST	n/a	n/a	0.388
8:10	SEPTEMBER	n/a	n/a	0.815
18:10	OCTOBER	2.277	0.131	n/a
2:2	NOVEMBER	n/a	n/a	1
13:7	DECEMBER	n/a	n/a	0.263

3rd Reef

F:M	MONTH	*G* Stat Williams	*p*	Binomial *p*
3:3	JANUARY	n/a	n/a	1
1:7	FEBRUARY	n/a	n/a	0.070
5:4	MARCH	n/a	n/a	1
6:4	APRIL	n/a	n/a	0.754
4:1	MAY	n/a	n/a	0.375
5:2	JUNE	n/a	n/a	0.453
1:0	JULY	n/a	n/a	1
0:4	AUGUST	n/a	n/a	0.125
1:6	SEPTEMBER	n/a	n/a	0.125
4:0	OCTOBER	n/a	n/a	0.125
2:0	NOVEMBER	n/a	n/a	0.5
1:0	DECEMBER	n/a	n/a	1

Appendix K-2. Seasonal results for expected vs. observed frequencies of *U. jamaicensis* sex ratio on three reef tracts in Broward County. *G*-test conducted for all months with sample size $n > 25$ and binomial probability test for all samples sizes $n < 25$. Significant deviations from a 1:1 ratio are highlighted in bold. Total combined sex ratio for all three reefs is also provided.

1st Reef

F:M	Season	*G* Stat Williams	*p*	Binomial *p*
20:8	**Spring***	5.220	**0.022**	N/A
60:46	Summer	1.273	0.259	N/A
33:22	Autumn	1.846	0.174	N/A
22:15	Winter	2.182	0.140	N/A

2nd Reef

F:M	Season	*G* Stat Williams	*p*	Binomial *p*
21:29	Spring	1.273	0.259	N/A
21:26	Summer	0.715	0.398	N/A
28:22	Autumn	2.182	0.140	N/A
46:40	Winter	0.417	0.519	N/A

3rd Reef

F:M	Season	*G* Stat Williams	*p*	Binomial *p*
15:9	Spring	N/A	N/A	0.308
6:6	Summer	N/A	N/A	1
7:6	Autumn	N/A	N/A	1
5:10	Winter	N/A	N/A	0.302

Total Reef Sex Ratio

F:M	Reef	*G* Stat Williams	*p*
127:99	1st	3.470	0.063
116:117	2nd	0.004	0.948
33:31	3rd	0.062	0.803

Appendix L. Total monthly size class observations (n = 609) of *U. jamaicensis* for three reef tracts in Broward County. Measurements are in total length (mm); class 1 (<150), 2 (150-199), 3 (200-249), 4 (250-299), 5 (300-349), 6 (350-399), 7 (400-449), 8 (450-499) 9 (500+) -.

1st Reef

Month	1	2	3	4	5	6	7	8	9	
JAN	0	0	0	0	3	1	3	0	0	7
FEB	0	1	4	2	9	8	0	0	0	24
MAR	0	0	0	1	0	1	1	1	0	4
APR	0	0	0	1	4	6	3	0	0	14
MAY	0	0	1	1	4	4	6	0	0	16
JUN	1	2	0	6	13	18	3	1	0	44
JUL	0	0	2	3	9	17	3	1	0	35
AUG	0	4	4	7	9	14	9	4	0	51
SEP	0	1	1	1	9	8	1	0	0	21
OCT	0	0	0	3	11	11	6	2	0	33
NOV	0	0	0	0	1	2	1	0	0	4
DEC	0	1	0	0	1	4	1	0	0	7
	1	9	12	25	73	94	37	9	0	**260**

2nd Reef

Month	1	2	3	4	5	6	7	8	9	
JAN	0	0	1	4	10	9	7	1	1	33
FEB	0	0	1	4	13	11	4	2	1	36
MAR	0	0	0	1	15	9	4	1	0	30
APR	0	0	0	2	5	2	0	0	1	10
MAY	0	0	0	1	5	5	0	0	0	11
JUN	0	0	1	5	7	6	1	0	0	20
JUL	0	1	5	6	3	10	6	0	0	31
AUG	1	0	0	5	5	4	2	0	0	17
SEP	0	1	0	2	12	5	1	0	0	21
OCT	0	3	2	2	11	9	6	0	0	33
NOV	0	0	0	0	1	2	1	0	0	4
DEC	0	0	2	4	6	8	0	0	0	20
	1	5	12	36	93	80	32	4	3	**266**

3rd Reef

Month	1	2	3	4	5	6	7	8	9	
JAN	0	0	0	1	4	0	1	0	0	6
FEB	0	0	0	3	3	1	1	1	0	9
MAR	0	0	0	0	5	4	1	0	0	10
APR	1	0	0	0	5	4	1	0	0	11
MAY	0	0	1	1	0	5	0	0	0	7
JUN	0	0	2	2	2	5	0	0	0	11
JUL	0	1	0	0	1	0	0	0	0	2
AUG	0	2	3	0	2	1	1	0	0	9
SEP	0	0	1	0	5	3	0	0	0	9
OCT	0	1	0	1	2	1	1	0	0	6
NOV	0	0	0	0	0	2	0	0	0	2
DEC	0	0	0	0	0	1	0	0	0	1
	1	4	7	8	29	27	6	1	0	**83**

Appendix M. Monthly ratios of Non-gestating (**N**) to Gestating (**G**) female *U. jamaicensis* for all three reef tracts in Broward County, FL.

	1st Reef	2nd Reef	3rd Reef	
Month	**N:G**	**N:G**	**N:G**	**Total**
January	1:2	13:7	3:0	26
February	6:2	12:1	1:0	22
March	1:1	8:3	4:1	18
April	3:6	4:1	5:1	20
May	1:8	0:5	2:2	18
June	9:7	3:5	5:0	29
July	7:12	5:4	1:0	29
August	17:8	2:2	0:0	29
September	9:1	3:5	1:0	19
October	17:4	12:6	2:1	43
November	1:1	0:2	1:1	6
December	3:0	7:6	0:1	17
	75:52	69:47	26:7	**276**